STANFORD RESEARCH INSTITUTE
MENLO PARK CALIFORNIA

February 1963

RADIOLOGICAL MONITORING: CONCEPTS AND SYSTEMS

Prepared for:

OFFICE OF CIVIL DEFENSE
DEPARTMENT OF DEFENSE
WASHINGTON, D.C.

By: Richard B. Bothun and Richard K. Laurino

SRI Project No. IMU-4021

Approved:

Robert A. Harker

ROBERT A. HARKER, DIRECTOR
MANAGEMENT SCIENCES DIVISION

This report has been reviewed in the Office of Civil Defense and approver' for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

ABSTRACT

Guidelines for design of radiological monitoring systems were developed from an analysis of the radiological information requirements over time of the principal organizational elements of civil defense, with respect to the emergency and recovery phases. Constraints on the design criteria of both fixed and mobile systems were defined as dictated by the information which they must provide. Fixed monitoring systems were studied with respect to station spacing, intensity reporting levels, accuracy of equipment, and related design specifications. The operational constraints and the techniques of deployment of mobile systems were also considered. Specifications of instrument accuracy were developed from considerations of both the accuracy with which dose can be related to the biological effect and the precision of radiological information required to support civil defense operations. The functions of monitoring instruments within shelters were reviewed, and their requirements for accuracy and range were developed. Initial investment and annual operating costs were estimated for selected systems.

PREFACE

This report is submitted to the Office of Civil Defense under Contract No. OCD-OS-62-135, Task I. The scope of the work was stated as follows: "Review and evaluate the existing and programmed civil defense radiological monitoring system; redefine the operational requirements for radiological information at local, regional, and national levels of civil defense; investigate the logistical problems of procurement, storage, maintenance, calibration, information utilization, and training; and summarize the capabilities, limitations, and potential costs of alternative radiological monitoring systems employing manual survey methods."

The subject matter of this report is oriented primarily toward the operational requirements for radiological information, monitoring systems, and information utilization. A companion report, Logistical Aspects of Existing Radiological Monitoring Instruments by F. D. Witzel, February 1963, treats the problems of storage, maintenance, calibration, and related subjects. Both reports consider monitoring system costs.

CONTENTS

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

TABLES

TABLES

I INTRODUCTION

Effective civil defense operations for survival and recovery from a nuclear war are highly dependent on the ability to function in the presence of fallout and to take appropriate measures to counter its hazards. These procedures require a definition of the fallout situation by means of radiological monitoring systems. The basic principles involved in the measurement of fallout hazards are well understood. A wide variety of instruments and measurement systems have been developed for civil defense during the past several years; these permit considerable latitude in techniques that can be adopted to carry out radiological monitoring. Each technique, of course, has inherent limits with respect to accuracy, cost, equipment complexity, and other significant constraints. But within these constraints, a wide choice is nevertheless possible. The question is simply which of the systems and measurement techniques are most appropriate to civil defense in supporting survival and recovery operations. This research,therefore, was undertaken to develop the guidelines and to identify the major parameters which should influence the choice of monitoring systems for the support of civil defense.

The problem was approached by first identifying the functions of civil defense over time throughout the recovery period and relating these functions to the principal organizational elements of civil defense. The requirements for information to support these functions were then identified. While this analysis was focused on radiological information requirements, some consideration had to be given to nonradiological operational data to view radiological data within a realistic frame of reference. The operational characteristics which monitoring systems must possess to provide radiological data were determined from the definition of radiological information requirements. These characteristics were developed in terms of accuracy, range of measurements, and related factors of operational significance but not in detailed engineering design form.

Throughout the analysis major emphasis was placed on reducing the information requirements to the absolute minimum necessary to support the civil defense functions. This objective, of course, is reflected in the design and operational characteristics of the monitoring system. If more elaborate and detailed radiological information is desired and can be obtained from the monitoring system without increases in cost or complexity, there should be no objection. Information requirements which significantly increase costs should be carefully examined. Conversely, if the development of civil defense discloses no policy requirements for certain classes of data or other methods of acquiring these data become available, the findings here should be adjusted accordingly.

The analysis was directed primarily to the civil defense organization and monitoring systems to be implemented in the late 1960's and beyond. A basic assumption throughout the entire analysis is that the civil defense organization and the general public will be thoroughly trained, highly motivated, and wholeheartedly in support of the civil defense program.

II SUMMARY

To support civil defense survival and recovery operations, radiological monitoring systems must provide information describing the hazards from fallout. The scope and character of the operations that an organization is capable of executing establishes the requirements for information from a monitoring system. The nature of these operations varies with respect to the time after attack or the phase of recovery and with the civil defense organizational level.

The basic functions of civil defense survival and recovery operations can be divided into four categories and identified with four organizational elements by which the civil defense command and operational structure can be defined. The organizational elements are identified by the functions they represent. Essentially, Administrative Command includes national, regional, and, to a lesser extent, state commands. Operational Command pertains primarily to local command levels, especially county and city organizations, although certain elements of state command might be included. Civil defense units are characterized by fire and police departments and rescue cadres. Population groups in the early portions of the emergency pertain to the shelter organizations. Later when the shelters are evacuated they may supplement the civil defense units. The functions of all organizational elements except Administrative Command are considered to be associated with the planning and execution of survival and recovery actions within the general scope of civil defense only. Administrative Command, on the other hand, includes the nation's highest ranking authorities whose decisions affect both civil and military actions. Thus, the characteristics of radiological information to support Administrative Command can be expected to extend beyond the limits arising from its civil functions alone.

Typical functions are summarized in Table I for each recovery period following the start of a war. These functions characterize the command and operational responsibilities of civil defense in the process of survival and recovery from the total range of hazards--not from fallout alone. Obviously, any operational decision or recovery plan must be made within the context of the complete hazard situation. Thus, the total information requirements to support each of these functions extends beyond the range of radiological data alone.

The characteristics of the radiological information required to support these functions are constrained by at least five significant factors. The first is time. The accuracy, level of detail, and other parameters of the radiological data will depend to a significant extent upon the time at which the civil defense function

Table I

FUNCTIONS OF THE CIVIL DEFENSE ORGANIZATION IN SURVIVAL AND RECOVERY OPERATIONS

Organizational Element	Recovery Phase			
	Attack and Shelter	Initial Recovery	Reconstruction	Final Recovery
Administrative Command	Area warning Damage and casualty assessment Establish early plans, policies, and regulations for support emergency operations Provide public information	Determine status of population and resources Establish policy and provide guidance for recovery Coordinate operational commands Allocate resources Provide public information	Determine status of population and resources Formulate long-range recovery plans Allocate resources Public information Adjust radiological regulations	Determine status of population resources Continue long-range plans Establish limits and control biological system uptake of radionuclides Public information
Operational Command	Disseminate warning Assemble and deploy operational units Determine status of operational units, population, and resources Advise administrative command of status on request or by doctrine	Assemble and vector operational units Determine status of population and resources, report to administrative command Implement actions specified by administrative command Instruct and provide guidance to the population	Establish and enforce regulations and operations within policy guidance of high command Determine status of forces and report to administrative command	Determine status of population and resources and report to administrative command Implement policies of administrative command
Operational units	Assemble at designated locations Determine status and advise operational command Gain access to hazardous areas as required by mission Instruct and aid population	Determine status and advise operational command Gain access to hazardous areas as required by command Perform assigned missions Instruct and aid population	Implement policy and carry out missions specified by command	Follow guidance from higher authority
Population groups	Assemble in shelter locations Determine status and report to operational command Group control Self help	Determine status and report to operational command Group control Self help	Follow guidance from higher authority	Follow guidance from higher authority

Source: Dr. Carl F. Miller, "Outline of Research Program Content for Civil Defense," prepared for the Office of Civil Defense by Stanford Research Institute, 1962.

must be executed after a war begins. Moreover, the information channels through which the data are acquired by the proper organizational element will be similarly affected by time. Organizational elements that are required to discharge certain functions in the early time periods must utilize monitoring and communication systems which either are independent of other organizational elements or are operated on a common-user basis with provisions for priority of service for each organizational element. Accuracy must be sacrificed for speed. Information to support long-term or delayed functions can be acquired by the organizational element through the normal reporting procedures within the chain-of-command. Because all organizational elements have planning or operational functions in the attack and shelter phase, all must have radiological information in this period.

The second constraint on radiological information is the ability to relate dose to the consequent biological effect. For the support of civil defense functions, radiation measurements must be sufficiently accurate to permit division of the range of biological effects into states or quanta which have operationally significant differences. The definition of these groups will change with time as one recovery phase supersedes another. In the early phases when the principal hazard is whole-body gamma radiation, the biological effects can be divided into at least five levels as a function of dose. These are:

Hazard State	Dose Limits (roentgens, ERD)	Biological Effect
Peacetime	0-12	None
Nominal	12-50	None
Noncritical	50-200	Limited radiation sickness, no medical care required
Critical	200-1000	Casualties and fatalities, medical care required
Extreme	> 1000	Immediate death

Third, radiological information should be consistent with other classes of command and operational data and of equivalent accuracy and detail. Area monitoring systems need to provide radiological information of the same accuracy as the degree to which the location and shelter condition of the population in the area are known. Monitoring systems to support operations, such as remedial evacuation, should provide radiological data of an accuracy and detail commensurate with that of the logistic and related information required to conduct the operation. In other words, no decision or action is taken on the basis of radiological information alone but rather within the context of the total hazard environment.

Fourth, the capability of an organizational element to utilize radiological information and take corrective action must exist in order to justify its need for data. Administrative Command can only use information on the fallout situation in terms of broad hazard states in the early periods of the attack and shelter phase. It can use little if any raw or unprocessed radiological information in subsequent periods. Rather, information is required on the status of the population and resources of the nation as provided by lower echelons. Operational Command and civil defense operational units require radiological information for controlling operations.

Finally, the characteristics of radiological information and the method of its acquisition are determined by the variability of the environment. Monitoring in an urban area cannot be conducted in the same manner as in open country and acquire information of the same accuracy. Each type of environment creates certain unique constraints on the monitoring techniques which are used to achieve a description of the radiation field. Monitoring procedures also differ between the period of fallout build-up and the subsequent time of decay and comparative stability.

The monitoring facilities to provide the required radiological information in support of the civil defense functions consist principally of two types of fixed monitoring systems and three configurations of portable equipment with a variety of communication facilities for use by operational units and mobile — land and aerial— monitoring teams and for installation in shelters. The characteristics of these are summarized in Table II as a function of the organizational element supported.

These systems and equipment configurations are utilized at different times throughout the recovery phases as the civil defense functions and information requirements evolve. The time-phased use of these systems to support the four organizational elements is illustrated in Figure 1.

Administrative Command in the early periods of the Attack and Shelter Phase must acquire radiological information through a fixed monitoring system consisting of a grid of stations placed throughout the nation or at least at points which are critical to early survival of the nation and to support of the military effort. The stations should report directly to command headquarters with no intervening command unit processing, summarizing, or delaying the acquisition of radiological data. Subsequent to completion of the early functions of warning, initial damage assessment, and related tasks as shown in Table I, Administrative Command has no continuing requirement for intensity measurements. Rather, information to support Administrative Command through the remainder of the recovery phases should concern the status of the population and resources and be provided by Operational Command and other lower echelons. Service group reports of the hazard status from radionuclides in biological systems during the

Table II

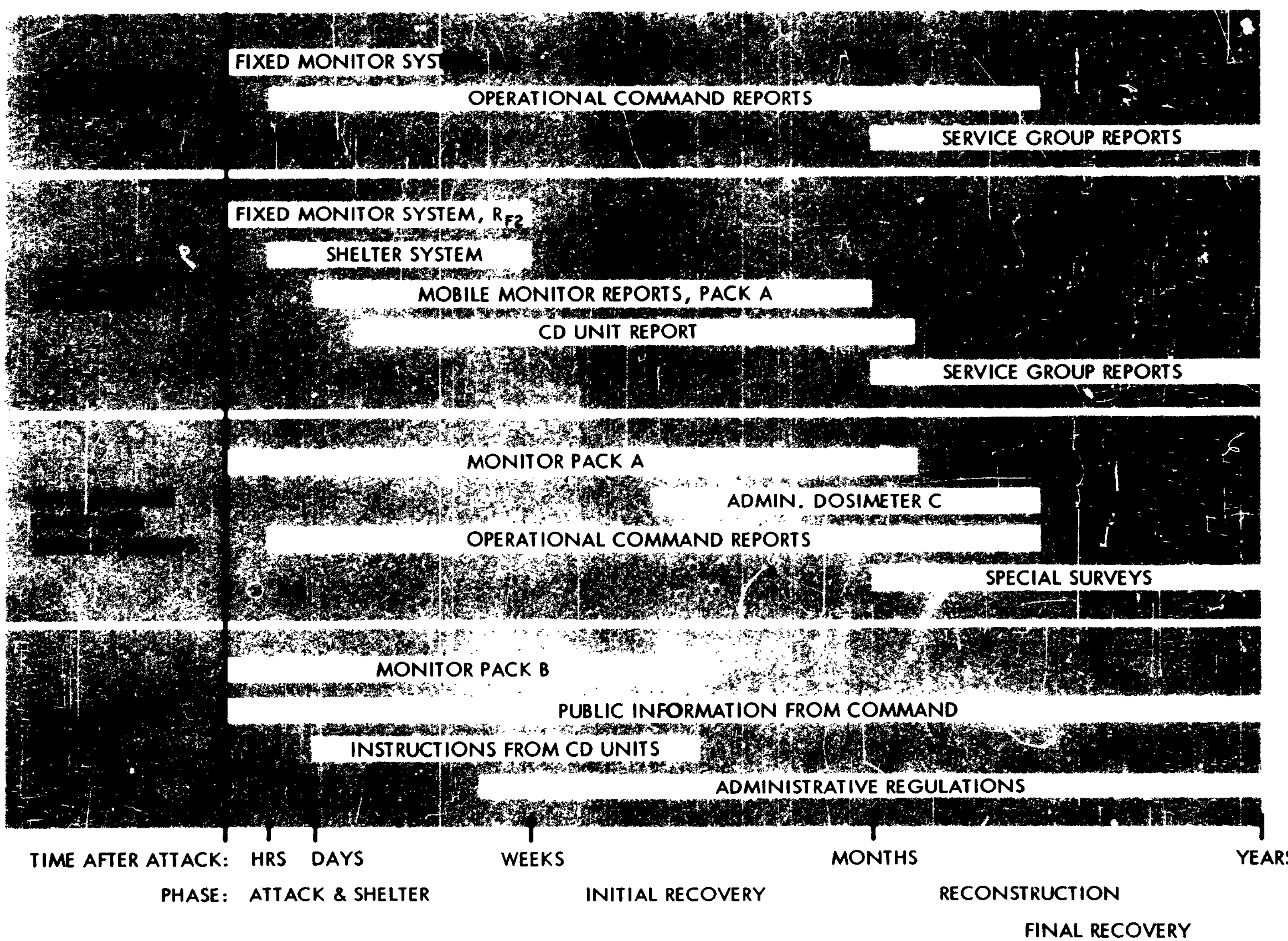
SUMMARY CHARACTERISTICS OF RADIOLOGICAL MONITORING SYSTEMS TO SUPPORT CIVIL DEFENSE

	Number of Units	Range	Accuracy[a]	Mode of Operation	Message Form	Reporting Doctrine
Administrative Command--Fixed System R_{F_1}	1,000-2,000 monitoring points distributed throughout the nation	1-10,000 r/hr	±50%	Manual or automatic	Voice, teletype, or digital for manual systems; digital for automatic	Report at hazard-state threshold or upon interrogation
Operational Command--Fixed System, R_{F_2}	10-30 monitoring points per urban area	1-1,000 r/hr	±50%	Manual or automatic	Voice for manual system; analog or digital for automatic	Report at each hazard-state threshold or upon interrogation
Operational Command--Shelter System	All shelters authorized, stocked, and formally recognized by civil defense agencies	See Monitor Pack B	See Monitor Pack B	Manual	Voice	Report at each hazard-state threshold inside shelter or upon interrogation
Operational Command--Land Mobile Monitoring	Variable (1 vehicle per team)	See Monitor Pack A	See Monitor Pack A	Manual	Variable, nonautomatic	Variable
Operational Units--Organic Equipment	Variable	See Monitor Pack A	See Monitor Pack A	Manual	Variable, nonautomatic	Variable
Operational Command--Aerial Monitoring	Variable	Depends on height of flight of aircraft	±50%	Manual	Variable	Variable
Monitor Pack A						
Gamma dose rate meter	1 per section[b]	0.1 to 50 r/hr	±50%			
Gamma dosimeter, nonself-reading[c]	1 per man	25 to 200 r	±35%			
Gamma dosimeter, self-reading	1 per section	1 to 200 r	±35%			
Monitor Pack B						
Gamma dose rate meter	At least 2 per shelter[d]	0.1 to 50 r/hr	±50%			
Dosimeter, self-reading	At least 2 per shelter[d]	1 to 200 r	±35%			
Low range beta dose rate meter	1 per shelter[e]	0.10 to 50 mr/hr	±50 to 100%			
Administrative dosimeter C[c]	1 per person assigned to work in radiation area	1 to 25 r	±50%			

a. Measurement accuracy with respect to the heterogeneous field; see Section III for discussion of this and calibration accuracy of instruments.
b. Section is that portion of the unit or group that is to operate independently or at some distance from the rest of the group.
c. These instruments serve the primary purpose of providing information to Command on the status of forces over extended periods; nonself-reading instruments are suitable for this function.
d. One instrument for shelter area and one additional for each group undertaking simultaneous sorties.
e. Class A and B shelters only.

Source: Derived by Stanford Research Institute.

Figure 1
TIME-PHASED SOURCES OF RADIOLOGICAL INFORMATION



Final Recovery Phase may be reported directly to Administrative Command as part of normal public health procedures.

Operational Command should acquire early radiological information from a fixed monitoring system established within its area of jurisdiction. Typically, 10 to 30 stations at spacings of 2 to 3 miles will adequately cover these areas. Fixed monitoring systems for Operational Command serve to provide information for early planning and initial deployment of operational units. Casualty and fatality information can be acquired by direct reports from shelters supplemented by area monitoring reports. The fixed monitoring system is supplanted by mobile monitoring procedures and reports from operational units in the late periods of the Attack and Shelter Phase and beyond.

Civil defense operational units and service groups require organic monitoring equipment to maintain close control of each individual unit. Countermeasures which are both radiological and nonradiological in nature are carried out within the limits and objectives established by Operational Command. However, each unit must have the capability of making on-the-spot decisions concerning routes through hazardous areas and precise stay times, as well as otherwise exercising tactical control in contaminated areas.

Population and shelter groups require monitoring equipment to implement self-help actions within the shelter and to report their status to Operational Command. Generally, during the Initial Recovery Phase and beyond, population groups operate in conformance with administrative regulations promulgated by command. The need for radiation information is minimal.

The general pattern of flow of information within the civil defense organization is summarized in Figures 2A-2D. As noted above all organizational elements in the early Attack and Shelter Phase require independent methods of monitoring the radiological environment in order to discharge their respective functions. In the early phase the flow of information from high to lower echelons consists primarily of warning; in the late Attack and Shelter Phase, as shown in Figure 2B, warning is replaced by planning and policy guidance. Administrative Command relies to a far lesser extent on the fixed monitoring system, R_{F1}, and instead utilizes status-of-forces reports from Operational Command in discharging its function.

Figure 2C illustrates the information flow during the Initial Recovery Phase. Operational Command acquires radiological information primarily through mobile monitoring systems. Information requirements of Administrative Command are satisfied by status reports from Operational Commands. These reports are developed from local status reports from operational units and the population groups.

Figure 2A
PATTERN OF INFORMATION FLOW IN THE EARLY ATTACK AND SHELTER PHASE

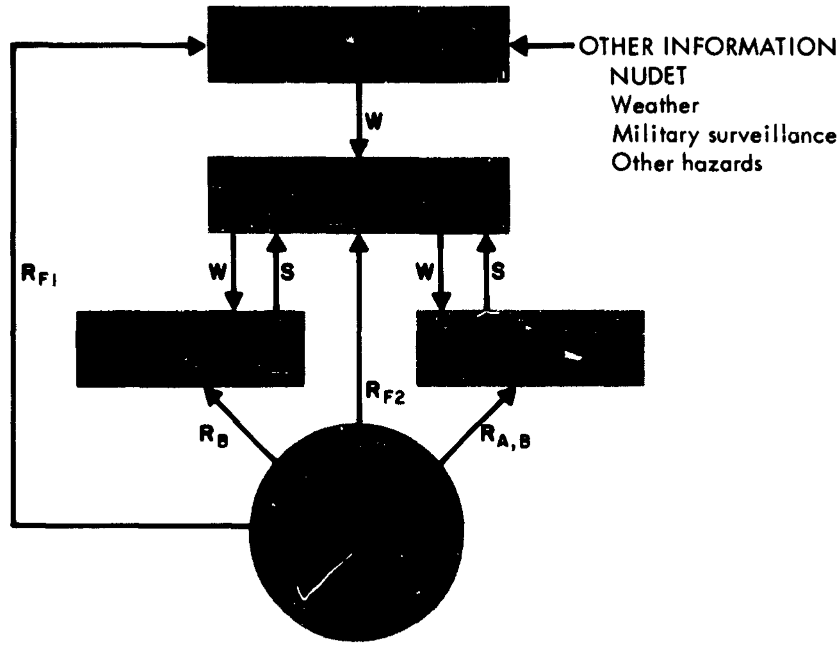
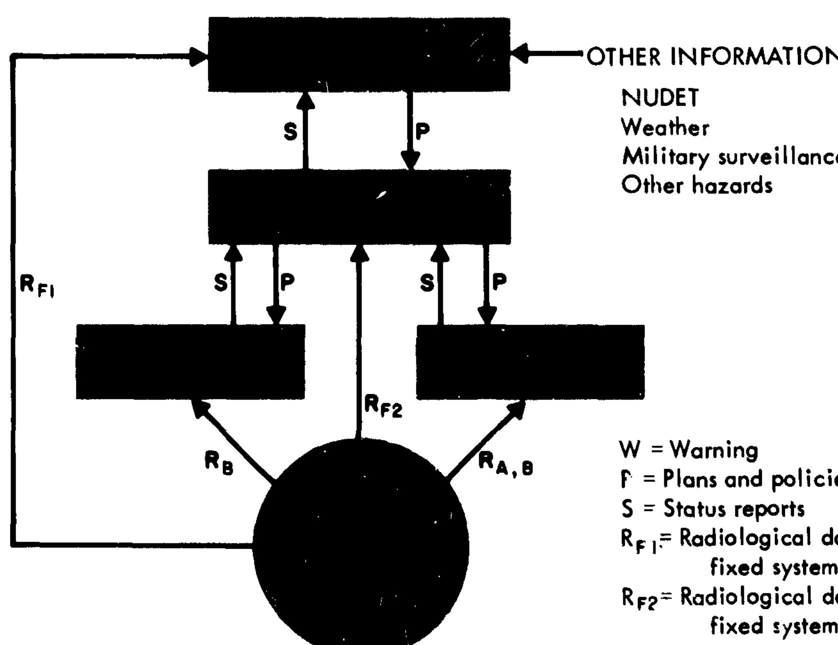


Figure 2B
PATTERN OF INFORMATION FLOW IN THE LATE ATTACK AND SHELTER PHASE



W = Warning
P = Plans and policies
S = Status reports
R_{F1} = Radiological data-fixed system, national
R_{F2} = Radiological data-fixed system, local
R_A, R_B, R_C } = Radiological data, manual system, using packs A, B, C

Figure 2C
PATTERN OF INFORMATION FLOW IN THE INITIAL RECOVERY PHASE

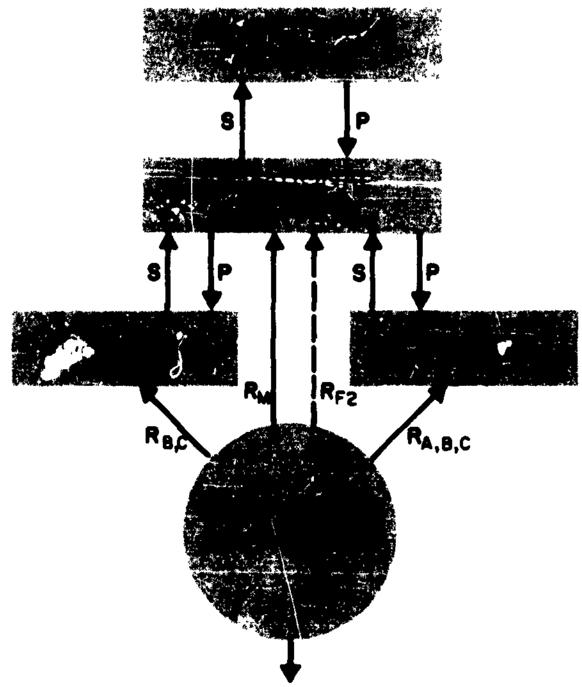
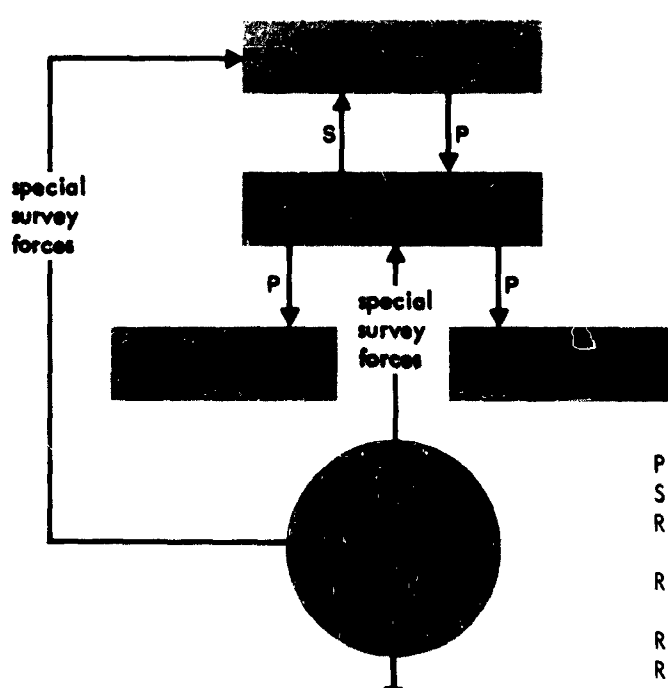


Figure 2D
PATTERN OF INFORMATION FLOW IN THE RECONSTRUCTION AND FINAL RECOVERY PHASES



P = Plans and policies
S = Status reports
R_{F2} = Radiological data, fixed system
R_M = Radiological data, mobile system
R_A, R_B, R_C = Radiological data, manual systems using packs A, B, C

In the Final Recovery Phases, as shown in Figure 2D, both command levels monitor the radiological environment. In this case, monitoring is conducted primarily to control the hazards of radionuclides in biological systems rather than to control gamma exposure.

Mobile monitoring systems include land and aerial techniques and support Operational Command and operational units. Mobile monitoring should be regarded basically as a tactical system under the control of Operational Command to be deployed as the need arises within the local area or upon request from Administrative Command. Because mobile monitoring generally cannot be initiated until the end of the fallout period, the requirements for radiological information by command in the early periods must be fulfilled by other systems. Administrative Command requires raw radiological information in the early periods only. By the time aerial monitoring procedures could be initiated and substantial areas surveyed, Administrative Command would have little need for the data and its information requirements would have shifted to the form of status reports forwarded through the chain of command.

The cost of a fixed monitoring system to support Administrative Command varies principally with the number of stations and the communication system linking the stations to command headquarters. Unit costs of the stations are estimated as follows:

	Initial Investment	Annual Operating Cost
Manned Station		
Special Structure	$3,300	$110
Class A Shelter	710	110
Automatic Station	1,460	160

The initial cost of the special-structure manned station is over twice that of the automatic station because of the need for a high-protection-factor shelter. If, however, manned stations can be located within class A shelters, the costs should be reduced by almost a factor of 5 from the special-structure station. Total costs for stations spaced at intervals of 30, 50, and 70 miles throughout the nation are shown below in millions of dollars.

	Initial Investment			Annual Operating Cost		
	30 Miles	50 Miles	70 Miles	30 Miles	50 Miles	70 Miles
Manned stations	$11.0	$4.0	$2.0	$0.4	$0.1	$0.07
Special Structure Class A Shelter	2.3	0.9	0.4	0.4	0.1	0.07
Automatic stations	4.8	1.8	0.9	0.5	0.2	0.1

Communication system costs depend on the detailed design of the network. For full-period leased circuits the annual costs in millions of dollars for the three station spacings are estimated below:

Station Spacing	Cost per Year
30 miles	$13.1
50 miles	11.8
70 miles	10.9

These costs are based on the assumption that in the 70-mile system each station is linked directly to the command headquarters by a separate circuit; in the 50-mile pattern two stations report per circuit; and in the 30-mile spacing six stations report per circuit.

Similar unit station costs apply to fixed systems to support Operational Command. In the range of 10 to 30 stations per local area, the total initial costs per area will vary from about $15,000 to $45,000 for the automatic system and between $33,000 to $100,000 for a system of special-structure manned stations using specially constructed monitoring-point shelters. If fixed monitoring stations are integrated with Class A shelters and are equipped with remote-reading instruments, the costs can be reduced significantly. The initial investment for a 10-station system is estimated to be $4,100 and the annual operating cost to be $900. Communication costs to serve monitoring systems in local areas could have a wide range. If the stations are linked to Operational Command headquarters by conventional private-line drops protected by line-load control procedures, the costs should be relatively minor. On the other hand, if full-period leased circuits are employed the costs will be of appreciable size.

The costs of monitoring equipment for mobile survey, operational units, shelters, and other uses, such as decontamination and reclamation, must be taken within the full context of civil defense operations. The instruments for these uses are generally interchangeable and universally applicable to most monitoring operations.

III CONCEPTS OF RADIOLOGICAL DEFENSE AND RADIOLOGICAL DEFENSE MONITORING

The concepts of radiological defense and civil defense have been evolving over a number of years. Some of the more basic concepts were included in operational guides and research papers dating back as much as a decade.* At present, most of these concepts are rather familiar to the technical community concerned with civil defense problems. It is therefore not necessary to attempt to review these concepts in detail. Some consideration, however, must be given to them since they are directly related to many conclusions with respect to radiological defense monitoring. The presentation in this section is therefore not concerned primarily with the development of the concepts of radiological defense or civil defense but with the derivation of corollary concepts for radiological defense monitoring.

The conclusions developed for radiological defense monitoring basically assume that the accepted concepts of radiological defense and civil defense have in fact been integrated in the civil defense organization at all levels. That is, it is assumed that the necessary staffing, training, and facilities have been provided and the associated command-control relationships have been developed. Since the present civil defense organization will probably be working toward this goal for several years, not all of the conclusions with respect to radiological monitoring can be considered to be currently applicable. It is expected that the conclusions would aid in future research and development on monitoring systems, with the understanding that implementation would be in phase with the development of the operational organization itself.

Biological Effects and Radiation Measurements

A rather general agreement prevails that radiation measurements are for the determination of hazards for the past, present, or future to people in the

* The earliest operational guide treating these problems in a comprehensive manner was Radiological Defense, Vol. II, published in November 1951 by AFSWP. Perhaps the most influential early technical paper on concepts was W. E. Strope, Radiological Defense Measures as a Countermeasure System, USNRDL-TR-74, February 1956.[1] (See list of references at the end of this report.)

presence of radioactive fallout. Considerably less agreement exists as to what constitutes the hazards and as the conditions under which these hazards should be measured.

There are at least five important types of radiation injury: radiation sickness, somatic effects, genetic effects, radiation dermatitis, and internal radiation injury. The degree of injury might range from a temporary slight depression of white blood cell count to immediate incapacitation and death. While all the types and degrees of damage are important, only a few conditions need be considered as operationally distinct. It is only necessary to distinguish between those conditions that change the operational conditions significantly and possibly call for a change in operational response. Operational distinctions of this type have often been made; perhaps the most notable recent effort was by the National Committee on Radiation Protection (NCRP).[2] The committee distinguished five injury groups for radiation sickness and three groups for radiation dermatitis. These are summarized in Table III. A clear implication of this and other efforts is that one of the principal purposes of radiation measurement is to aid in identifying a given hazard with the appropriate injury group.

The most basic operational distinction is between significant and nonsignificant hazards. Such distinctions are derived from the concept of the hazard environment. The term "hazard environment" is used in this report to refer to those hazards (both radiological and nonradiological) that are accepted as part of the background conditions under which operations are performed. The hazard environment will of course vary with the urgency of the over-all situation. The greater the urgency of the operational situation, the greater the radiation hazards that would be tolerated. This point is illustrated by the fact that emergency gamma dose tolerances exceed peacetime tolerances by a factor of 100 to 1,000.

In these terms, hazards that exceed the hazard environment by an appreciable amount can be considered significant. Some types of significant hazards can be reduced to the background level by the use of routine modifications of operational procedure, such as the use of special clothing to protect from skin contamination. Other significant hazards that cannot be handled by routine modifications of operational procedure might be considered as the proper subjects for radiation measurement.

The concept of the hazard environment also tends to emphasize that hazards other than radiation are likely to exist in wartime emergency situations. Decisions would generally be based on the over-all hazards present. Consequently, radiological information alone would generally not be sufficient to permit effective decision or action. In many instances where a decision is based on the evidence of more than one type of hazard, the most suitable to minimize one hazard might be incompatible with the reduction of the others--e.g., the decision to remain in shelter in face of a fire hazard versus evacuation through a high radiation

Table III

SUMMARY OF RELATIONSHIP BETWEEN DOSE AND INJURY

TYPE OF EXPOSURE	TYPE OF INJURY	MEDICAL CARE REQUIRED	ABLE TO WORK	PROBABLE MORTALITY RATE[1]	COMMENT
A. Brief, whole-body, γ-rays					
12-50 r	Asymptomatic	No	Yes	0	Similar effect from ERD of 12-50 r
50-200 r	Acute radiation sickness, Group I	No	Yes	Less than 5 percent	Similar effect from ERD of 50-200 r
200-450 r	Acute radiation sickness, Group II	Yes	No	Less than 50 percent	Probably similar effect from ERD of 200-450 r
450-600 r	Acute radiation sickness, Group III	Yes	No	More than 50 percent	Uncertain effect of ERD in excess of 450 r
More than 600 r	Acute radiation sickness, Groups IV and V	Yes	No	100 percent	Uncertain effect of ERD in excess of 450 r
B. Internal Deposit	Acute radiation sickness, with severity proportional to internal dose	Varies	Varies	Varies	No reliable data on relation between internal dose and whole-body brief external dose
C. Beta-irradiation of skin					
Less than 1,000[2] r	Radiation dermatitis, Type I	No	Yes	0	Associated with whole-body radiation dose of variable size
1,000-5,000 r	Radiation dermatitis, Types II and III	Yes	No	Less than 50 percent	Mortality related to area of burn
More than 5,000 r	Radiation dermatitis, Type IV	Yes	No	More than 50 percent	Mortality related to area of burn

SOURCE: National Committee on Radiation Protection, Bulletin Number 29, January, 1962

[1]This refers to acute mortality: death during first 6 months after onset of exposure.

[2]Beta-ray dose is usually stated in rads.

field. Under these conditions, the utility of radiation measurements, regardless of quantity and accuracy, would be limited by the accuracy and completeness of information about the other hazards entering into the decision.

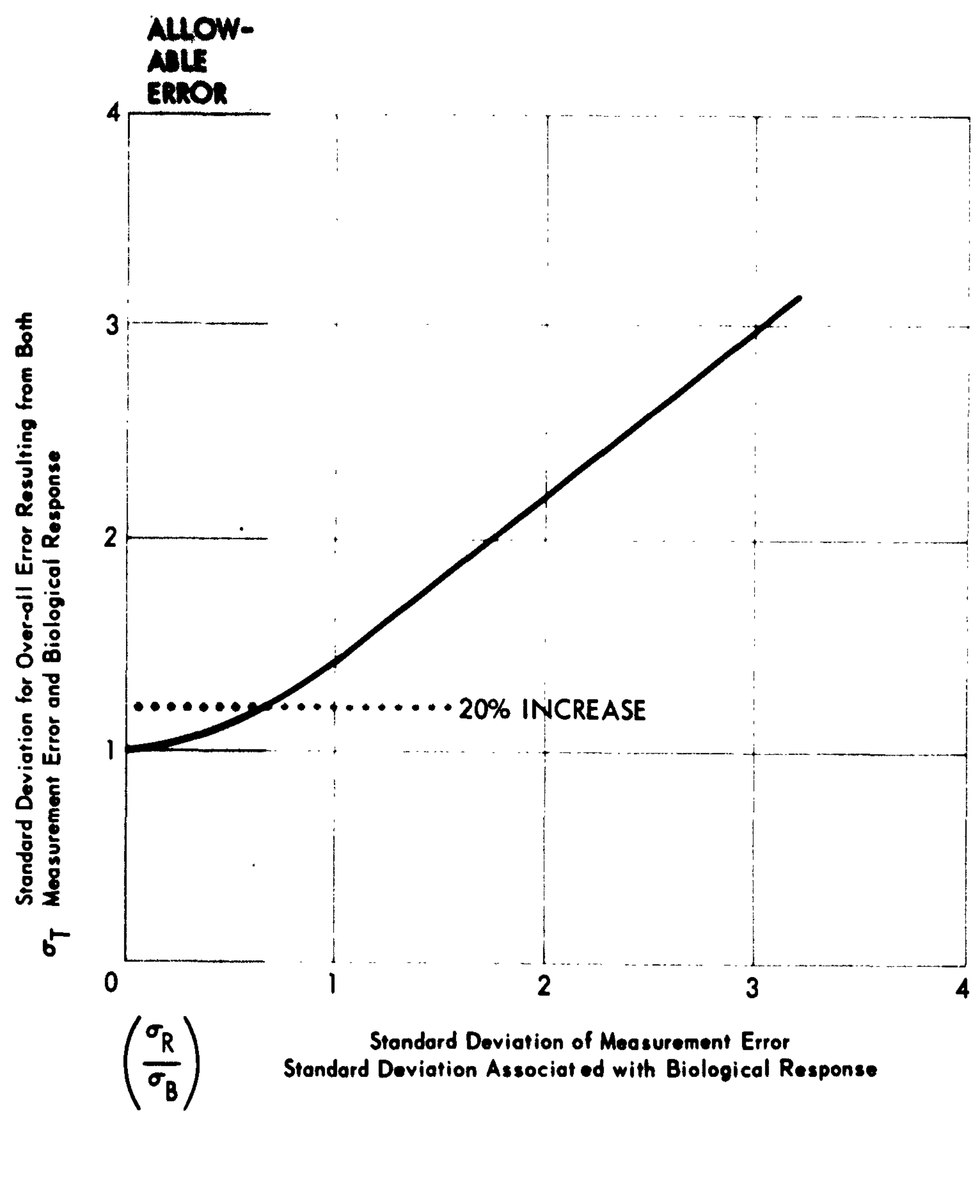
The degrees of hazard associated with a given radiation exposure have been summarized many times before and therefore do not require reiteration here. There is, however, one aspect of biological response to radiation that has not received sufficient attention with regard to the implications for radiation measurement. This aspect is the inherent variability of biological response of a heterogeneous population to a given exposure to radiation. For instance, for gamma radiation delivered in a short period (2 to 4 days), the probability distribution for fatalities or the fraction of fatalities versus dose is considered to lie between the effective limits of 200 and 600 roentgens. The variability for radiation dermatitis might be even greater--1,000 to 5,000 rads. The distribution curve for casualties or fatalities would be even more widely dispersed in any attack situation since many people would not be uniformly irradiated and others would be suffering from a combination of injuries.

The result of dispersion is to limit the utility of great accuracy and detail in making measurements for the purposes of predicting the outcome in terms of casualties. Figure 3 shows the effect on the predicted dispersion of the casualty curve as a function of the error or dispersion in the radiation readings. Small errors in radiation measurements as represented by a standard deviation do not cause an appreciable increase in the dispersion of the casualty curve. If a reasonable limit on additional dispersion of the casualty curve is allowed, for example 20 percent, then the allowable measurement errors--assuming that these errors are random--can be easily computed. For conditions where such calculations apply, e.g. predicting dose to personnel working in a radiation field or moving out of a field along a gradient, the allowable error range would be about 67 percent of the variability associated with biological response. For radiation sickenss the variability as indicated about the LD_{50} is ±50 percent, so that errors concerning doses that might result in casualties from this effect might be allowed to be as large as ±35 percent. The allowable error for measurements associated with radiation dermatitis might be even larger--±50 percent.

The allowable error in measurements for prediction of radiation sickness casualties is in good agreement with the estimated performance for radiation instruments. Conventional radiation instruments are generally rated as having an accuracy of measurement of ±20 to ±25 percent. Accuracy of prediction of dose as estimated by the NCRP is ±25 percent when based on dosimeters and ±35 percent when based on dose rate readings.* From these considerations, it would

*Accuracy here refers to measurements in a distributed radiation field resulting from fallout. The accuracy of the instruments with respect to a calibration source would, of course, be higher; the current standard for most civil defense instruments in the range of ±20 to ±25 percent appears to be adequate.

Figure 3
EFFECT OF ERRORS IN MEASUREMENT ON ACCURACY OF CASUALTY PREDICTIONS



appear that current gamma instrument accuracy is sufficient for the purposes of predicting biological effects on the population.

Hazard States

In a previous section it was indicated that one of the principal purposes of radiation measurement is to aid in identifying hazards with injury groups. The distinctions implicit in the definitions of injury groups can be carried a step further to provide definitions for those hazard conditions or hazard states that correspond to a given set of injury groups. In these terms, a hazard state may be taken to represent the range of radiation hazards that would lead to some operationally defined injury group, unless action were taken to reduce the hazard. More specifically, hazard states can be defined in terms of the range of doses that would lead to injury.

As in the case of the injury groups, some degree of judgment is required to establish the dose ranges associated with the hazard states. For instance, a group of hazard states could be established corresponding to the dose intervals for radiation sickness given in Table III. When the gamma hazard is negligible, hazard states might be defined in terms of the injury grouping given for radiation dermatitis or possibly in terms of internal hazards.

A breakdown of hazard states based on Table III is not rigid. The states can and should be so defined as to have both biological and operational meaning. Since operational decisions at early times after an attack will be based to some extent upon even less precise information concerning other hazards and operational conditions, a broader subdivision of the dose spectrum might be in order. Such a breakdown for operational decisions at early times is presented in Table IV.

Table IV
DEFINITION OF HAZARD STATES FOR RADIOLOGICAL FALLOUT

Hazard State	ERD Range (R)	Biological Effects
Peacetime	0-12	Acceptable under peacetime standards.
Nominal	12-50	No clinical effects.
Noncritical	50-200	Appreciable somatic and genetic effects. Some early clinical effects but no medical care required.
Critical	200-1,000	Casualties and fatalities from radiation sickness; medical care required.
Extreme	>1,000	Immediate incapacitation and death.

The table was obtained by using or combining injury groups given in Table III. The peacetime hazard state was included to indicate that there would probably be some uncontaminated areas in the continental United States and that the peacetime tolerances should be maintained if at all possible. In fallout areas, the nominal hazard state would be essentially incorporated into the hazard background. No systematic attempt to measure radiation would be justified in fallout areas at early times leading to doses of 12-50 roentgens.

The noncritical hazard state corresponds to the acute radiation sickness Group I in Table III. Doses of this magnitude would be accepted in emergency work in fallout areas; however, efforts would be made to measure or otherwise estimate such dosages since they cause an appreciable increase in genetic and somatic effects and determine the usefulness of personnel because of sensitivity to further exposures in fallout regions.

The critical hazard state corresponds to injury Groups II, III, and IV in Table III. Doses in the region would generally be undesirable even in emergency conditions in fallout areas. The main effect at early times should be devoted to identifying and characterizing areas containing a critical hazard state.

The extreme hazard state corresponds to injury Group V in Table III. Doses of this magnitude are unacceptable under any conditions; however, the fact that some persons might have been exposed to this amount prior to completing critical duties in industry, transportation, emergency services, and other functions would be a factor in determining the damage status of the locality.

The use of this or some similar set of hazard states has extremely important implications with respect to the required quantity and quality of radiological information. In this regard, it should be noted that the range of doses contained within one hazard state can vary by a factor of 4 or more. This would mean that even a few rather inaccurate measurements would be quite useful. For instance, the value of error of ±50 percent assigned to estimates of doses based on maps as suggested by NCRP* (i.e. fallout contours) would still give a very high probability of identifying the correct hazard state and would therefore permit decisions as to general feasibility of an action.

---

* Actually this estimate by NCRP would appear to be overly optimistic for contours in built-up areas; however, the argument would still hold with substantially larger errors.

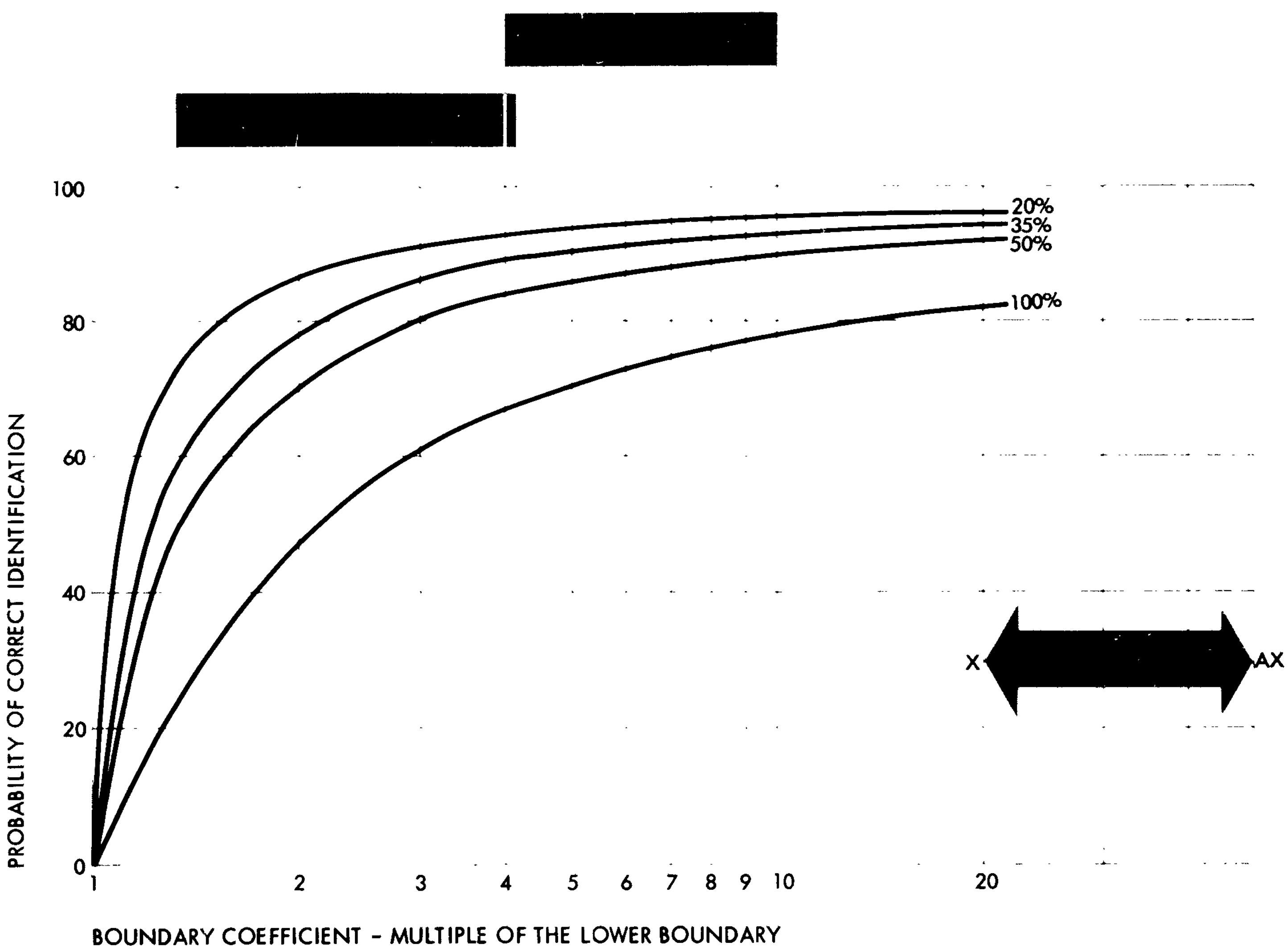
The success in predicting a correct hazard or injury group can be treated as a general problem of determining the probability that a random variable would take on a value within some given interval of values. If the dispersion parameter of the distribution of the random variable were directly proportional to the mean value then the probability of a successful prediction could be described for general classes of intervals. That is, the error in measurement could be described as a percentage of the intensity being measured. To understand the relationships involved, it is convenient to define the term "boundary coefficient" to be the ratio of the value of the upper boundary of the interval to the value of the lower boundary. For instance, an interval of 1-10 r/hr would have a boundary coefficient of 10. In these terms, the probability of successful identification of a hazard state interval with a given measurement error would be the same for all intervals having the same boundary coefficient. For instance, the probability of success with ±35 percent measurement error would be the same for all the following intervals: 1-10, 10-100, and 100-1,000.

The probability of successful prediction is given in Figure 4 as a function of the interval size expressed in terms of boundary coefficients for several error percentages. The probability of success was calculated on the assumption that the intensity measured was selected randomly from the interval and that the error in measurement is normally distributed around the mean equal to the actual intensity with a percentage error of two standard deviations as given.

Representations of this type can be used to illustrate the desirability of making predictions in terms of wide bands of effects, such as hazard states or gross injury groups. Generally, the wider the interval, the more likely that the prediction will be successful. The figure shows the band of conditions expressed as boundary coefficients associated with the injury groups suggested by NCRP and given in Table III and the hazard states given in Table IV. For intervals as large as those given for the hazard states (see Figure 4), the probability of successful estimates is uniformly large (above 80 percent) even with measurements in error by as much as ±50 percent. The probability of success for larger errors in measurement or estimation (±100 percent) lies in the range of 70 to 80 percent but probably would still be more often correct than other nonradiological information in early stages of the civil defense effort. The probability of success could be considerably less with smaller intervals, such as those given for some of the NCRP injury groups. The interval of 450 to 600 roentgens has a boundary coefficient of 1.3.* In some of these instances the probability of success is

* This NCRP interval would be easier to predict if the upper boundary of injury Group III were set at 1,000 r. It appears that this would not seriously impair the operational usefulness of the information.

Figure 4
PROBABILITY OF SUCCESS IN ESTIMATING HAZARD INTERVALS



50 percent or less, so that the value of the estimate might be rather marginal. Estimations of these groups with information containing errors between ±50 and 100 percent might be quite misleading. For instance, it is unlikely that a success prediction of injury Group III could be made solely on the basis of a location given with respect to a set of dose rate contours.

If the problem is considered from another standpoint, certain statements can be made about accuracy required to make successful estimates. With respect to the hazard states, accuracy of measurements or other information of ±50 percent would appear to be more than adequate. Consequently, accuracy of current dose and dose rate radiation meters would be satisfactory. With respect to the NCRP injury groups or smaller groups, accuracies of ±20 percent or better would appear to be desirable.* With current instrumentation, one or more accurate dosimeters would be required per person to achieve these specifications.

Environmental Conditions and Radiation Measurements

Fallout Patterns

The representation of a fallout pattern as a set of isointensity lines is perhaps the best publicized feature of a surface nuclear burst. Such representations have always had a place in technical studies and in operational problems. The reason that fallout contours have been useful in operational problems is not difficult to determine. Basically, the fallout contours summarize a great amount of point detail data (i.e. radiation measurement at points) in a form that is readily assimilated by command. For a single burst, the drawing of such lines is in effect a graphical summation process. The lines tend to place bounds on the regions subjected to a given radiation level or higher, even though irregularities are often missed or conveniently smoothed out. When such contours are superimposed on the map of an area, they give command an immediate comprehension of the magnitude and seriousness of the radiological problem.

The merits of the fallout contour representation are considerably diminished when the radiological conditions are produced by overlapping patterns from

---

* Accuracy of ±35 percent would appear adequate if the interval for Group II were changed to 450-1,000 r since all boundary coefficients would be 2 or greater.

two or more surface nuclear bursts. Most investigators of targeting problems would agree that such overlapping patterns are more likely to be the rule than the exception. The reasons for this conclusion are: (1) most valuable target areas contain more than one aim point, and (2) many aim points are assigned more than one weapon. Arrival time for weapons in the same area might differ by several hours to one day or possibly even longer. These conditions will produce considerable difficulty in applying decay corrections necessary to the representation of the contours. In addition, erratic patterns might be produced due to displaced ground zeros and shifting wind patterns during the period between weapon arrivals.

It is doubtful whether any research group has been able to take all these factors into account when developing simulated fallout environments. It is, however, instructive to consider the fallout pattern as it might appear from a simultaneous attack of several surface detonated weapons. Figure 5 indicates such a pattern for a portion of the eastern United States. No obvious structure appears in the pattern. Areas of a given intensity are no longer bounded by a single isointensity line. Closed contours must be interpreted with great care since in some cases they are inverted and enclose areas of lower rather than higher intensity. This loss of structure to the pattern would invariably increase the requirements for measurements While the pattern from a single weapon first might be approximated by a handful of measurements (tens of readings), the representation of the complex pattern would require an order of magnitude increase in measurements over the same area (hundreds of readings). In addition, the already difficult problem of automatically producing contours from readings is made completely impracticable by the loss of pattern structure.

Although such patterns would still be a useful aid at the local level to indicate local field gradients and other features, it is clear that for higher command levels much of the value ascribed to the pattern from a single weapon would be lost in the representation of overlapping patterns. Consideration of other methods of representing the geographical character of the radiological environment would therefore be desirable. Such methods could be developed by using the same rationale that led originally to the fallout contour concept. Fallout contours were developed as an abstraction of the detail of individual readings. Since with complex events the contours become too complex for easy assimilation, a higher level of abstraction might be desirable. The next level of abstraction could represent the radiological environment not as geographical shapes but as an indicator of the highest hazard state expected in a suitably large geographical subregion. These comparative techniques are illustrated in Figure 6. In policy decisions, the requirement is seldom for knowledge of the infinitely many gradations of hazard in an environment but for a general comprehension of the severity of the problems in a region. In policy decisions, it is generally recognized that damage and danger are not restricted only to those immediately involved. Because of the interactions of a

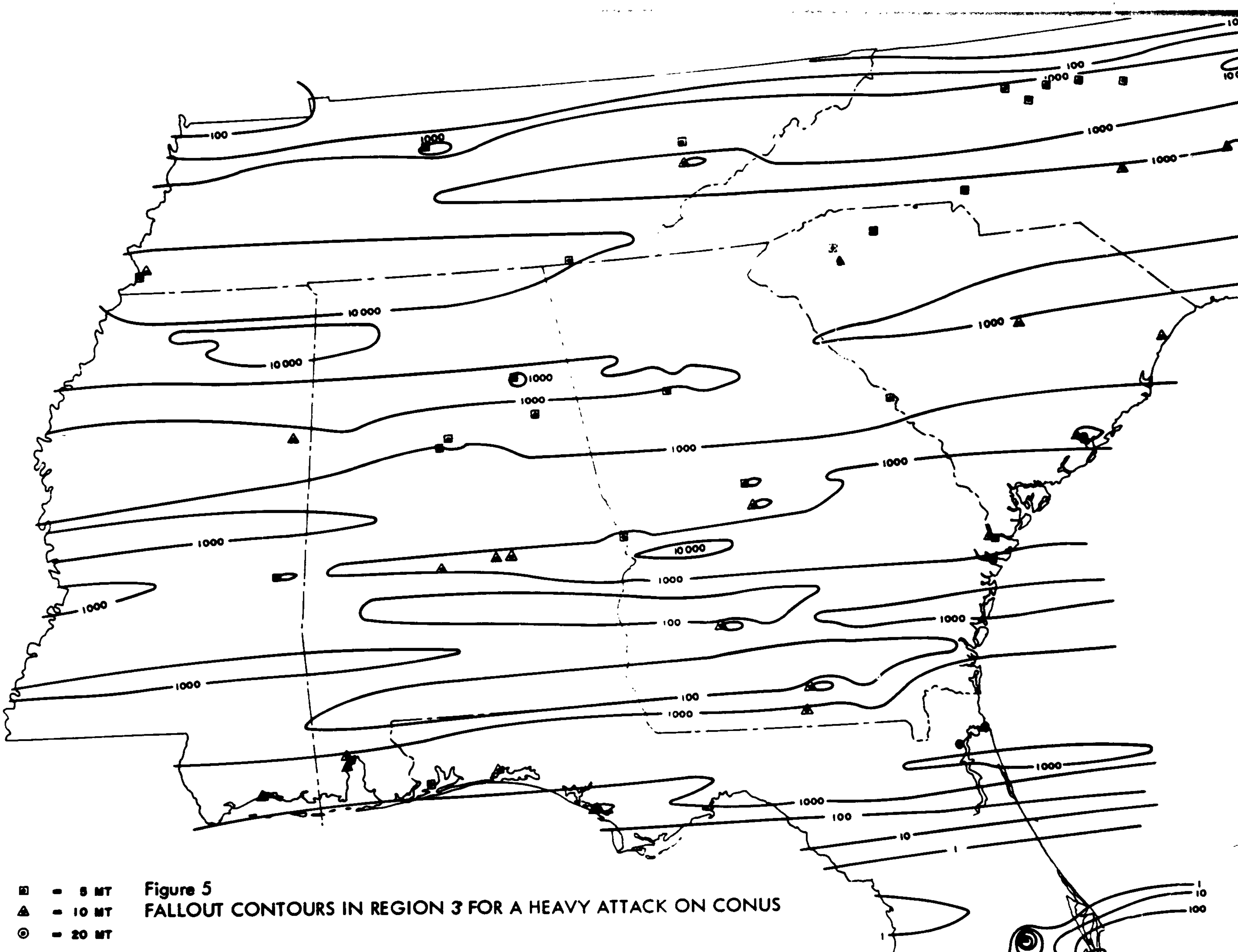
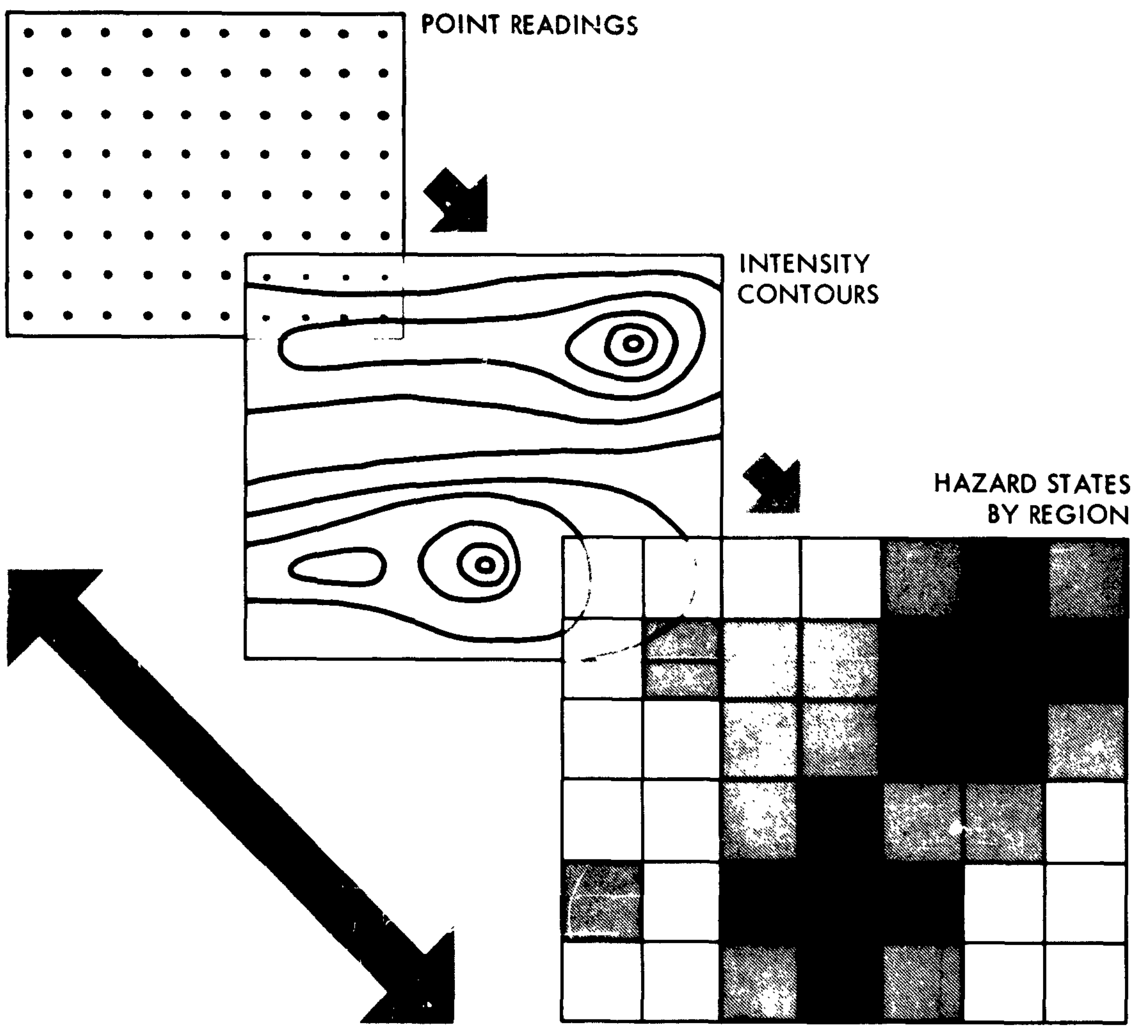


Figure 5
FALLOUT CONTOURS IN REGION 3 FOR A HEAVY ATTACK ON CONUS

Figure 6
COMPARATIVE LEVELS OF ABSTRACTION IN THE DISPLAY OF GEOGRAPHICAL RADIOLOGICAL INFORMATION



complex society, groups outside the immediate problem area would also be affected. These considerations tend to justify the representation of a substantial geographical area in terms of a single hazard state. Standardized geographical subregions, however, would be desirable as an aid to data handling and processing.

Dynamics of the Fallout Event

The characteristics of the radiation contours that are evolving during the period when the fallout is arriving are subject to even greater uncertainty than that ascribed to the completed contours. However, even order-of-magnitude estimates of some of the important characteristics during the dynamic phase are useful in developing basic concepts for radiological defense and radiation measurement.

Perhaps the most important single characteristic is the time element--that is, arrival and duration of the radiological events. For the large-yield weapons of primary interest, a substantial period of time might elapse between detonation and arrival of fallout downwind and the duration of fallout at a given point and over the entire area could encompass a considerable period of time. For large yields, times-of-arrival might vary from less than one hour close to the burst to about 24 hours at the downwind extremity of the 100-roentgen-per-hour standard intensity contour.* The duration of the fallout period might range from about one hour to as much as twelve hours. Times of this magnitude are appreciable in terms of the intervals required for some civil defense actions, such as partial evacuation, shelter, and industry shutdown. Fallout predictions for this period based on fallout models have been recognized to be important. It would be desirable, however, to increase the accuracy** of such methods by incorporating early radiation measurements made downwind from detonations.

A second important implication for radiation measurement is the limitation on making measurements from unshielded locations during the dynamic period. Due to the possibility of very high hazards during this period, the important measurements must be made from well-shielded locations for a period of 24 hours or longer after initiation of the attack. The length of this period might be doubled if allowance is made for the attack to develop over a reasonable time. These conditions sharply reduce the utility of mobile monitoring--land and air--during this early period.

---

* Standard intensity refers to field radiation intensity at some point after completion of fallout corrected to H+1 hours.

** The models are based on assumption of surface bursts and fraction fission, both of which may be seriously in error.

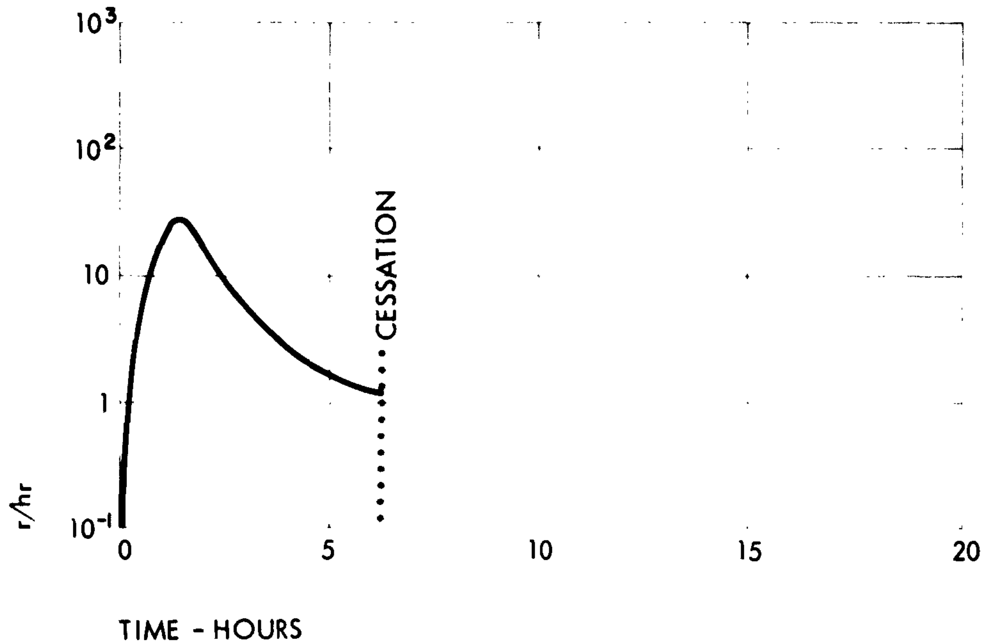
Another important factor influencing measurement requirements is dose rate history at a point during the fallout event. Point dose rate histories have often been represented[3] by a sharply rising curve, as shown in Figure 7, reaching a maximum somewhere between one-fourth to one-half of the fallout period followed by a period of less rapid decline to a value of perhaps one-third to one-fourth the peak intensity. These presentations might tend to imply that accurate calculations of dose were possible during the period of fallout arrival. The detonation of several weapons in the same target area over a period of a number of hours could result in point dose rate histories that were quite irregular as indicated in Figure 7. Several peaks in the dose rate history corresponding to the arrival of the main body of fallout from the individual shots might be observed. Contributions from shots at greater distances might simply change the rate of decline of the dose rate at later times during the dynamic event. As a result of these uncertainties, it must be concluded that accurate prediction of gamma dose during the dynamic period of the fallout event is not possible regardless of the number and accuracy of measurements or the sophistication of the prediction models and data processing techniques.

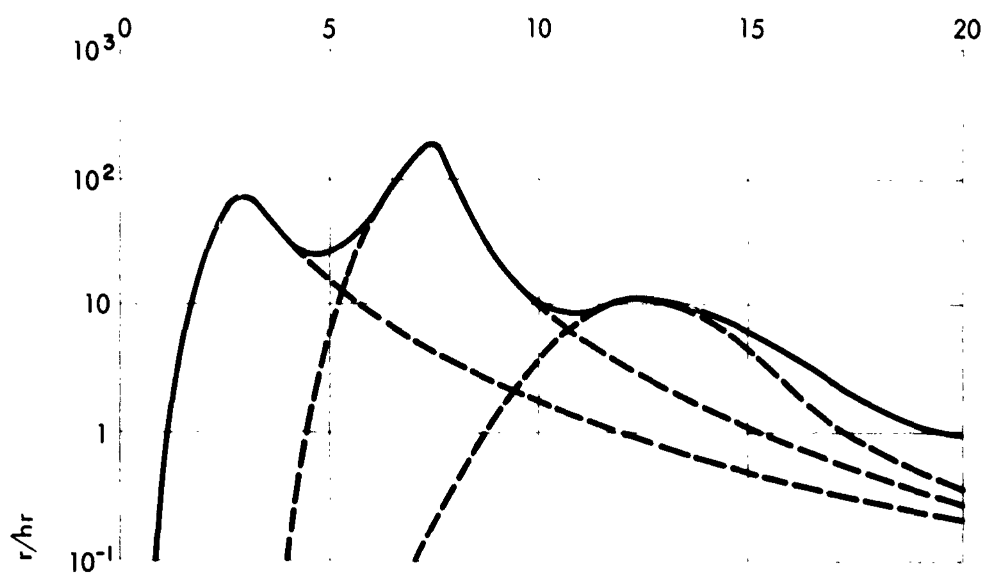
The problem of uncertainty of this type is, of course, not unknown in other disaster situations (e.g., the problem of predicting the river crest height and time in the middle of a prolonged rainstorm). Some useful prediction can be made in such circumstances, provided the meaning of prediction is understood and subsequent actions are guided accordingly. Generally speaking, the most simple, and in this case probably the mose useful, technique would be to employ some variety of persistence prediction. In this approach, future hazards would be estimated in terms of the consequences of a persistence of hazard conditions at the time of the estimate or in terms of the persistence of the rate of change of hazard conditions given at the time of the estimate. Since the error could be quite large, the degree of accuracy should be indicated by making predictions in terms of general estimates, such as hazard state, rather than in terms of equivalent residual dose or similar measure.

Influence of Microscopic Properties of the Fallout Field

The detailed or microscopic properties of the fallout field will have an important influence on requirements for radiation measurements. The gamma radiation at a specific point in the field consists of radiations emitted by the radioactive material deposited on the surrounding exposed surfaces. For measurement at the standard 3-foot height above the ground, most radiation would originate within 200 to 300 feet of the measurement location.[4] The relative contributions of the radiating surfaces to the dose rate at the point of measurement depends on the distance, amount of material deposited, and the amount of intervening shielding. In open, unpaved areas, where most of the field measurements for land surface bursts have been made, a reading in one location

Figure 7
TIME-INTENSITY RECORDS FOR SINGLE AND MULTIPLE FALLOUT EVENTS





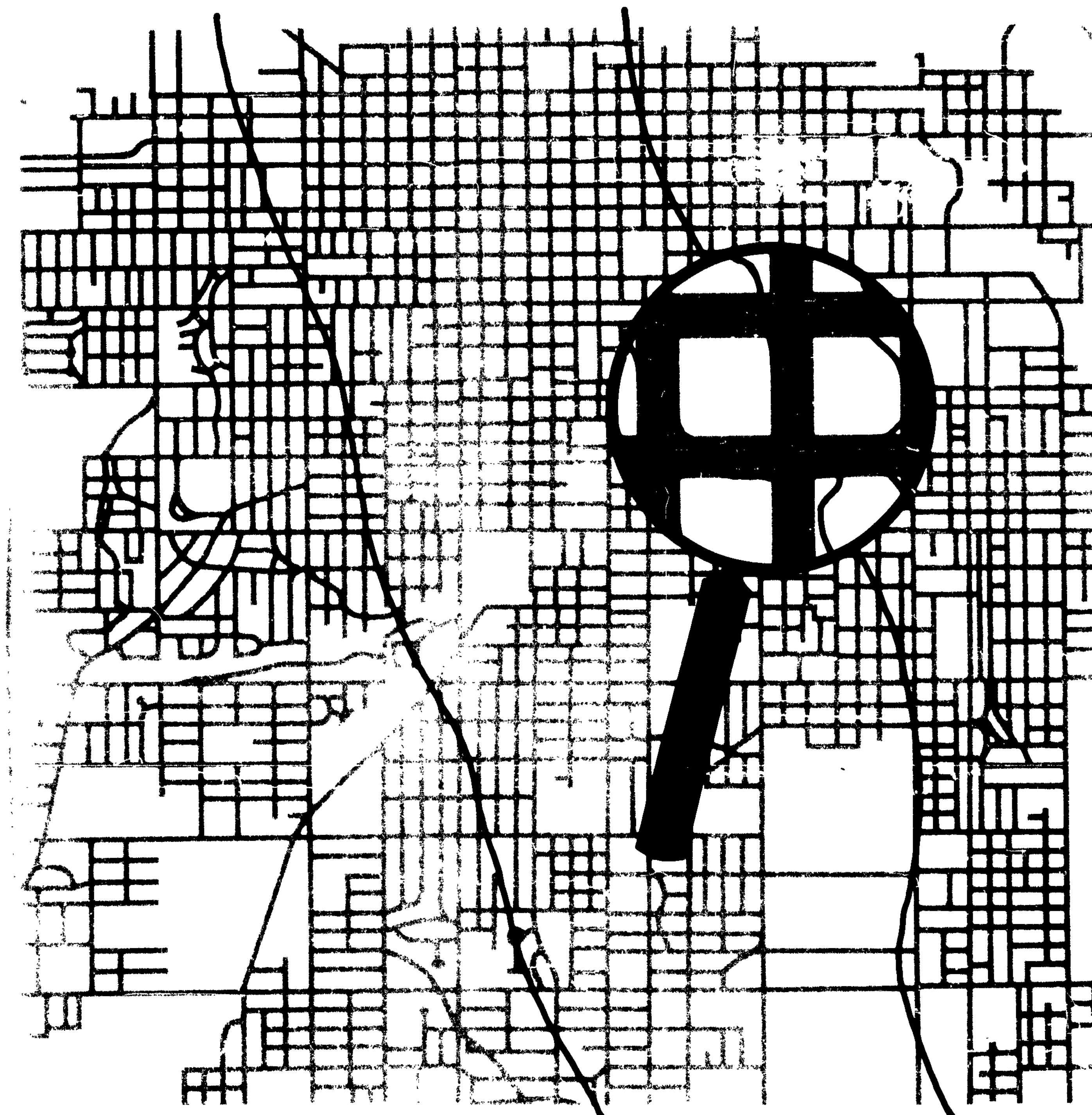
can generally be taken as being representative of the field in the immediately surrounding area, since the landscape and fallout conditions are reasonably uniform. In built-up areas, a single measurement might not be very representative of the surroundings, due in part to the great variety of source geometry and shielding that would generally exist in the vicinity. Readings should be made, therefore, in locations with quite similar geometries, such as in the centers of intersections, in parks and playgrounds, so that the readings can be related to one another. This fact also indicates that many important locations, such as the immediate area around shelters, would not necessarily be satisfactory monitoring locations.

Irregularities in deposition of fallout material in built-up areas would limit the applicability of a single radiation measurement. Irregular deposition can be caused by abrupt changes in air direction due to small-scale obstructions from buildings, bridges, and other objects. The general result would be to impact the larger fallout particles on the windward side of surfaces. Eddy currents might also cause high deposits to be formed on the leeward side of some structures.[5,6]

In one test the windward side of trees exhibited a radiation intensity twice as high as that of the leeward side. In addition, migration of fallout may occur after initial deposition by the action of wind or rain. Smooth paved areas might be blown clean and the fallout particles collect along curbs and other obstructions at the edge of the areas. Migration on unpaved areas is generally slight. Rainfall might cause erosion of fallout material from paved areas and roofs and concentrate the material in poorly drained spots.

These irregularities, which are noted for built-up areas, tend to blur the concept of the radiation contour. In open areas, where the concept has been successfully applied, the radiation contour was, in fact, a line of equal intensity with some degree of uniformity of intensity immediately adjacent to it. This picture has little meaning when applied to the contour in built-up areas. A microscopic view of the designated contour line shown in Figure 8 would generally reveal a complex, fine structure of isointensity lines enclosing small regions which vary in intensity by a factor of two or more. It is unlikely therefore that predictions of dose in built-up areas could be made within ±50 percent as suggested by NCRP. A more realistic estimate would allow an error factor of two or greater. Errors of this magnitude cause estimates given in terms of roentgens to be rather misleading. Estimates from contours phrased in terms of hazard states would recognize the basic uncertainties and serve as a restraint against over-control of operations by command. In those instances where more accurate information is required for actual performance of countermeasures and other operations, measurements at the location and along the route of movement would be necessary.

Figure 8
FINE DETAIL OF A RADIATION CONTOUR IN AN URBAN AREA



Civil Defense Countermeasures

A primary purpose of radiation measurement is to support countermeasure action in the presence of fallout. The major types of countermeasures are well known and include shelter, decontamination, and remedial evacuation. The applicability of any countermeasure depends upon the degree of hazard which, in turn, is related to the time elapsed since initiation of the attack. The applicability of countermeasures as a function of the time after attack has been studied for many years. It has often been found convenient to consider countermeasure actions in terms of operational phases since a given operational phase and associated countermeasures can generally be considered to have common objectives.[1,7,8] A recent extension of the operational phase concept by Miller[9] seems to offer the best description to date of the total civil defense effort. A brief summary of the four operational phases--attack and shelter, initial recovery, reconstruction, and final recovery--is presented in Table V. It will be noted that the objectives of civil defense change with the shift of the operational phase from the initial objective of population survival to interim rehabilitation and finally to complete reconstruction and elimination of radionuclides from biological systems.

This shift in objectives which accompanies the shift in operational phase means a change in emphasis with respect to countermeasure actions and the associated radiation measurements. The emphasis during the attack and shelter phase is on high-range gamma field measurements for assessing survival probabilities for population groups and civil defense units during and immediately after the dynamic phase of the radiological events. In the initial recovery phase gamma field measurements are of primary importance for planning recovery operations and supporting these operations after they are undertaken. Emphasis during the reconstruction phase is on routine gamma dosage control for workers and population groups in reclaimed areas. Monitoring during the final recovery phase is concerned with laboratory measurements and special field surveys to recognize and eliminate dangerous radionuclides from biological systems. These monitoring operations are summarized in Table VI. As indicated in the table during the first three phases, field beta surveys are predominant in nonfallout areas for handling evacuees, preventing spread of contaminants, and similar actions. The special surveys for food and water have application to both fallout and nonfallout areas during the reconstruction phase and the final recovery phase.

The effectiveness and efficiency of some radiological countermeasures have often been described in a degree of detail unknown for more conventional disaster actions.[4,10,11] In these descriptions of radiological countermeasures, an effort has been made to present reasonably simple planning information by placing the emphasis generally on the average or expected outcome of application of the countermeasure. While such emphasis is certainly justified for advanced

Table V

CIVIL DEFENSE OPERATIONAL PHASES

Phase	Begins	Ends	Objective	Principal Countermeasures
Attack and shelter	Attack warning	Short-term actions outside shelter	Survival	Shelter Mobilization Rescue Medical aid Damage control Movement control
Initial recovery	Short-term actions outside shelter	Stay time not restricted	Interim reclamation for short-term survival	Gross decontamination Damage repair Mobilization Allocation cf resources Movement and control Medical care Public health Debris clearance
Reconstruction	Stay time not restricted	Completion of reconstruction	Restore physical and social structure of nation	Construction Allocation of resources Medical care Debris clearance Rehabilitation Public health Special reconstruction and disposal
Final recovery	Stay time not restricted	Indefinite	Eliminate radionuclides from biological systems	Special decontamination and disposal Agricultural reclamation programs Food processing and grading Public health program

Source: Stanford Research Institute.

Table VI

PRIMARY MONITORING OPERATIONS IN FALLOUT AND NONFALLOUT AREAS

Operational Phase	Fallout Area	Nonfallout Area
Attack and shelter	Gamma dose rate: H.R., L.R. Gamma dose: H.R., L.R. Beta dose rate: shelter Class A and B only, L.R.	Beta dose rate: L.R., field[a]
Initial recovery	Gamma dose rate: L.R. Gamma dose: H.R., L.R. Beta dose rate: personnel decontamination only, L.R.	Beta dose rate: L.R., field Special surveys[b]
Reconstruction	Gamma dose: L.R. Special surveys Beta dose rate: L.R., field	Beta dose rate: L.R. Special surveys[b]
Final recovery	Special surveys	Special surveys[b]

Note: H.R. = High range readings: above 50 r/hr or above 50 r.
L.R. = Low range readings: below 50 r/hr or below 50 r.

a. Field survey refers to measurements of equipment, personnel, and structures made by civil defense units.

b. Special surveys include laboratory measurements, field measurement of food and water, and public health monitoring.

Source: Derived by Stanford Research Institute.

planning, the average or expected results do not provide a sufficient basis for determining accuracy and number of readings required for associated radiation measurements. To characterize the radiation measurements, it is essential to investigate the variability of results of application of countermeasures since variability in effectiveness and efficiency would result in a corresponding deviation of actual doses from those calculated on a basis of planning factors.

The data on variability of results are generally not reported as completely as is the average result of the application of a given countermeasure. However, the data available and the possible extrapolations from proposed actions do indicate that such variability can be extremely large. Estimates of variability for three important countermeasures--evacuation, shelter, and decontamination--are presented in Table VII. Under the assumption that all side conditions, such as soil and weather, are known, the dispersion induced by the countermeasures is roughly comparable--although somewhat higher--in magnitude with the dispersion currently attributed to radiation measurements or to biological variability. If all the side conditions under which the countermeasures are to be performed are not known, the variability in results can become extremely large--in the range of 100 to 300 percent.

The dispersions in countermeasure performance, taken together with the effect of biological variability, tend to widen further the tolerances on accuracy for supporting measurements. Even under the best of conditions, the dispersion of the casualty curve based on predictions of dose after application of countermeasures would be approximately 60 to 70 percent. Using the criterion suggested in Figure 3 and Table IV, the acceptable dispersion in radiation measurement accuracy for prediction purposes might be as great as 40 to 50 percent. In circumstances where detailed knowledge of the conditions is not available, the error in prediction of casualties would probably be too great for practicable purposes. However, even under these conditions the hazard state could generally be predicted to a sufficiently accurate degree to allow at least an estimate of the basic feasibility of the operation. As suggested previously, the detailed application of a given countermeasure generally should be the responsibility of the units on the scene assisted by detailed local monitoring.

It is useful to relate civil defense countermeasures to the hazard state concept. The objective of such countermeasures can in fact be defined in terms of hazard state. The objective of a radiological countermeasure is to reduce the radiological conditions by one or more hazard states. For instance, gross decontamination would endeavor to reduce the hazard state from the critical or noncritical hazard level to a lower state, such as noncritical and nominal, respectively. Radiological countermeasures in comparatively fallout free areas would be directed toward reducing all hazard states to peacetime hazard states. Table VIII presents the hazard-state objectives of various radiological countermeasures.

Table VII

ESTIMATED VARIABILITY OF EFFECTIVENESS OF SELECTED COUNTERMEASURES

Countermeasure	Deviation (Percent)	Comment
Evacuation		
Uniform gradient	35-50 %	Based on variation of walking rates only[1] Also corresponds approximately to military experience
Irregular gradient	≥100	Based on walking rates[1] and field variability[2]
Shelter		
Intraclass variability	≥200	Shelter class definitions[3]
Makeshift basement shelter	≥ 50	Highly variable; greater than 50 percent quite likely in vicinity of entrance and ventilation openings
Decontamination		
Land reclamation (known soil conditions)	50	Motor grader scraping[4]
Land reclamation (unknown soil conditions)	60-300	Motor grader scraping[5]
Asphalt and cement	50	Street sweeper[5]

1. M. N. Alexander, et. al., Effect of Population Mobility on the Location of Communal Shelters, Operations Research Office, Staff Paper 30 (ORO-SP-30), October 1957.
2. L. R. Donaldson, A Radiological Study of Rongelap Atoll, Marshall Islands, During 1954-1955, UWFL-42, University of Washington, August 1955.
3. Guide for Architects and Engineers, NP-10-2, Office of Civil Defense, May 1960.
4. C. F. Miller, Analysis of Radiological Decontamination Data Obtained from Field Tests, USNRDL-TR-321, April 1959.
5. H. Lee, et. al., Stoneman II Test of Reclamation Performance, Volume IV, USNRDL-TR-337, January 1959, and Volume III, NRDL-TR-336, June 1959.

Table VIII

HAZARD-STATE OBJECTIVES OF SELECTED COUNTERMEASURES

	Initial or Potential State	Final State
Attack and shelter phase		
Shelter: Class A	All states	Peacetime
Other classes	All states	Noncritical or lower
Fire fighting (NR)	Critical or lower	Noncritical or lower
Movement and control (evacuation)	Critical or higher[a]	Noncritical or lower
Rescue	Critical or lower	Noncritical or lower
Initial recovery phase		
Gross decontamination	Noncritical	Nominal or lower
Movement control	Critical or noncritical	Nominal or lower
Damage repair (NR)[b]	Critical or lower	Noncritical or lower

a. Movement in this case prior to fallout when potential hazard is as stated.

b. NR indicates that nonradiological countermeasures have, in addition to primary objective, a hazard control objective for civil defense personnel.

Source: Derived by Stanford Research Institute.

The definition of countermeasures in these terms suggests a basis for characterizing the associated radiation measurements. Since the objective is essentially to reduce the hazards from one state to another, the measurements used during the application of the countermeasures are for indicating the accomplishment of this transition. These measurements are therefore basically threshold measurements. In the case of decontamination, a dose rate characteristic of the boundary of a desired hazard state is specified. Then the countermeasure is applied until measurements indicate that the field has dropped below the specified boundary. The value of the threshold can be determined by advanced planning. However, the determination of the precise application of the countermeasure required to achieve the threshold or indeed the feasibility of actually achieving it is a function of the operational unit in the field and the associated monitoring personnel.

The relationship of hazard states to countermeasures is particularly fruitful in the case of the shelter countermeasure. The interrelation of the various shelter classes[11] with the outside hazard states defined earlier indicates the hazard state conditions likely to exist inside the shelter during the attack and shelter phase as shown in Table IX. The table indicates that the hazard state inside shelters can be predicted in many cases from information on the hazard state in open areas. In half of the hazard-state shelter conditions (15 cases), the conditions in the shelter would be known by command to be nominal without additional information from the shelter. In only 7 of the 30 possible conditons would there be uncertainty in command as to whether a critical or higher hazard state existed within shelters. This fact suggests that data for command on conditions in shelters need be obtained for only a fraction of the total shelters.

The range of uncertainty concerning the extreme hazard state in shelters suggests that defining additional hazard states with particular implications to shelters might be desirable. In Table X additional states at the higher end of the dosage spectrum are postulated. The extreme hazard state, or shelter state III, is limited to the range of potential dose of 1,000 to 10,000 r; shelter state II is assigned a range of dose of 10,000 to 200,000 r; and shelter state I is assigned a dose range greater than 200,000 r. Such values above a dose of 10,000 r appear necessary on the basis of current estimates of the magnitude of possible enemy attacks.

The advantage of limiting the upper bound of the extreme hazard state by providing additional states I and II is indicated by the decreased range of uncertainty in the event that the extreme hazard state (III) is observed by command. With the unlimited dose range (Table IX), command is uncertain with respect to the critical hazard state inside shelters for all important shelter types (A through E). With the limitation on the dose range (Table X) the uncertainty of command is only with respect to shelter types D and E. It

Table IX

SHELTER INTERIOR HAZARD STATES[a]

Outside Hazard State	Shelter Type A	B	C	D	E	F
Extreme (E)	PC	NC	NC	NC	SE	CE
Critical (C)	P	P	PN	PS	NC	SC
Noncritical (S)	P	P	P	PN	PS	NS
Nominal (N)	P	P	P	P	PN	PN
Peacetime	P	P	P	P	P	P

Note: A critical or higher hazard state may exist for those entrees enclosed in the box.

a One letter indicates only one hazard state possible under stated condition. Two letters indicate range of hazard states possible under stated condition.

Table X

EXTENDED SHELTER INTERIOR HAZARD STATES[a]

Outside Hazard State	Shelter Type A	B	C	D	E	F
Shelter state I (>200,000 r)	NC	CE	CE	E	E	E
Shelter state II (10,000-200,000 r)	PS	NC	SE	CE	E	E
Shelter state III (Extreme) (1,000-10,000 r)	P	PN	PS	NC	SE	CE

Note: A critical or higher hazard state may exist for those entrees enclosed in the box.

a. One letter indicates only one hazard state possible under stated condition. Two letters indicated range of hazard states possible under stated condition.

should be noted that use of additional states might require measurement of dose rates in excess of 1,000 r/hr. For instance, if knowledge is required of the existence of a critical hazard state in an adequate shelter, such as those with a protection factor of 1,000 or more, then outside dose rates as high as 10,000 r/hr might have to be measured. The dose rates associated with the hazard state boundaries under various conditions and as well as the possible reporting doctrine to be used will be discussed in Sections IV and V.

Organization in Civil Defense

The general organization of civil defense is indicated in the National Plan[12] which delegates responsibilities to various groups in the national, state, and local governments. Civil defense plans at all levels attempt to delegate responsibility by taking into consideration (1) the functions that various groups are best suited to perform and (2) political, geographic, and economic factors. The assignment of responsibility in any functioning organization is based to a considerable extent on the state of readiness of the various echelons. Since the state of readiness in the civil defense organization is expected to improve substantially over time, the actual assignment of responsibilities may also be expected to change. Of course, with each change in an organization there are new requirements for information at various levels and new channels of information flow. As a consequence, it is not feasible at the present time to set detailed information requirements for specific groups within the future organization.

While the actual responsibility in the civil defense organization can be expected to change over time, the basic functions to be performed by the organization will remain relatively constant. Therefore, if the organization is related directly to functions, some rather basic statements can be made about information requirements. For this purpose it is convenient to consider a functional organization for civil defense as composed of four basic parts: (1) Administrative Command, (2) Operational Command, (3) civil defense units (disaster services, police, fire, etc.), and (4) population groups.

There is no one-to-one correspondence between the actual and functional organizations of civil defense. National command level is primarily an administrative command; however, regional and state levels while largely administrative might have some operational responsibilities.* The local level

* In San Francisco, the mayor commands local disaster forces as well as those operational units of the state organization which are deployed locally since he is also considered to be the local state representative. See Operations Plan,[13] of the San Francisco Disaster Council and Corp.

of the present organization, including city, county, and similar elements, will be essentially an operational command; however, these levels also have some administrative responsibilities with respect to civil defense units under their cognizance and in support of higher (administrative) commands. Civil defense units include the disaster services and other units that either exist or will exist in later phases of the civil defense operation. These units are responsible for the detailed application of the countermeasures according to the general instructions given by the Operational Command. Population is included in the functional organization since it supports and is supported by other elements of the organization. In this sense, more than the officially recognized members of the community, such as wardens and shelter leaders, are included. Population as a whole is included since it performs a civil defense function by self-help and by providing information to command during the attack and shelter phase and by providing personnel for cadre organizations during the initial recovery phase of operations.

Administrative Command

The functions of an Administrative Command are to administer and support the operations of the civil defense organization. The major functions are:

1. Provide attack and fallout warning to operational commands (Phase I)*

2. Provide appropriate public information (all phases)

3. Institute general operational regulations (Phase II and later)

4. Formulate and initiate major policies and programs (Phase II and later)

5. Allocate resources to operational commands (Phase II and later)

6. Undertake long range planning (Phases III and IV)

7. Reassign responsibilities among operational commands (all phases)

8. Determine status of civil defense forces, population, and resources and report to higher commands (all phases)

---

* Phase I--Attack and Shelter
II--Initial Recovery
III--Reconstruction
IV--Final Recovery

The provision of attack and fallout warning to Operational Commands and appropriate information to the public are two functions to be performed by Administrative Command prior to and during the attack. National or Administrative Command should be in a position to provide information to Operational Command in local areas as to the likelihood of attack and the possible arrival times of fallout. This information could provide the basis for decisions by Operational Command as to the desirability of partial evacuation, taking shelter immediately, and other decisions of a tactical nature. These decisions would probably be the most crucial of those made by Operational Command during the entire civil defense operation.

To provide the necessary warning and related information, the national command must have current information on the development of the attack, including the likelihood of follow-on bomber attack, and on the development of the radiological events from weapons previously delivered. Under such dynamic conditions, military experience would dictate the establishment of independent sources of radiological information for Administrative Command by use of systems separate from those used by local operational groups.

Reassignment of responsibilities during the attack and shelter phase would probably only occur if it were established that the cognizant operational command was not functioning because of damage from the attack or because it had not been mobilized. Information on status of forces, population, and resources would be used in the attack and shelter phase primarily as an input to other national decisions, especially presidential decisions pertaining to the use of military forces, and possibly for public information. Planning for later phases of the civil defense operation could not be undertaken during the dynamic part of the attack and shelter phase even if the time were available since fallout might still be arriving in many localities and additional bursts might occur. Consequently, the information on the radiological situation required by Administrative Command during the attack and shelter phase would be of a very general nature such as that supplied by knowledge of the geographical distribution of hazard states.

A number of important functions begin in the initial recovery phase, including allocation of resources and the initiation of policies and programs. The nature of these functions is such that considerably more detailed radiological information is required than in the attack and shelter phase. In almost all instances the information would include data on nonradiological conditions as well. For instance, the allocation of resources would probably be based on a comparison of the requirements for recovery in various localities with the information on the current status of forces in those localities. Summary information on status and requirements can only be provided by Operational Commands. Consequently, in the initial recovery period and later, the primary source of radiological and nonradiological information for Administrative Command should come up through the organizational chain from Operational Commands. Under these

conditions, the independent monitoring system for Administrative Command has a primary function only in the attack and shelter phase; the characteristics of the information provided by the system should be compatible with the necessary functions of Administrative Command during this early phase. (See also Section IV.)

Operational Command

The responsibilities of Operational Command are to direct the employment of operational units in disaster areas and instruct the population. Included among the functions of an Operational Command are the following:

1. Assemble and deploy operational units (preattack, Phases I and II)

2. Determine status of civil defense units, population, and resources in area of cognizance and report to higher command (all phases)

3. Assign missions to operational units (all phases)

4. Instruct population groups in hazardous and nonhazardous areas (Phases I and II)

5. Vector operational units into fallout areas (Phases I and II)

6. Establish and enforce local regulations (all phases)

Operational Command has a number of critical functions beginning at or before fallout arrival and continuing through the initial recovery phase. On the basis of attack warning and information on fallout arrival, the Operational Command would give appropriate instructions to population, members of civil defense units, and industrial groups. In assigning missions to operational units, the Operational Command must assess the general feasibility of the proposed action, taking into account the radiological situation, physical damage, and status of the civil defense units. For vectoring operational units into the fallout area with maximum safety, the Operational Command requires rather specific information on (1) the geographical distribution of the radiation field, (2) non-radiological factors, such as the conditions of alternative transportation routes, and (3) the capability of the operational units to move according to schedule. To estimate status of population groups, civil defense units, and resources during the attack and shelter phase, Operational Command would require knowledge of the geographical distribution of the field and distribution of population supplemented by measurements made in the sheltered locations occupied by the population.

The close interrelation of radiological and nonradiological factors in the decisions of Operational Command during the first two phases suggests the accuracy and degree of detail of radiological data required at this command level. Prior to arrival of fallout, warning and other data may indicate the possible future existence of critical or higher hazard states. Times of arrival combined with the known types and distribution of shelters should provide a basis for such decisions as partial evacuation, assembly of civil defense units, plant shutdown, and other preparatory actions.

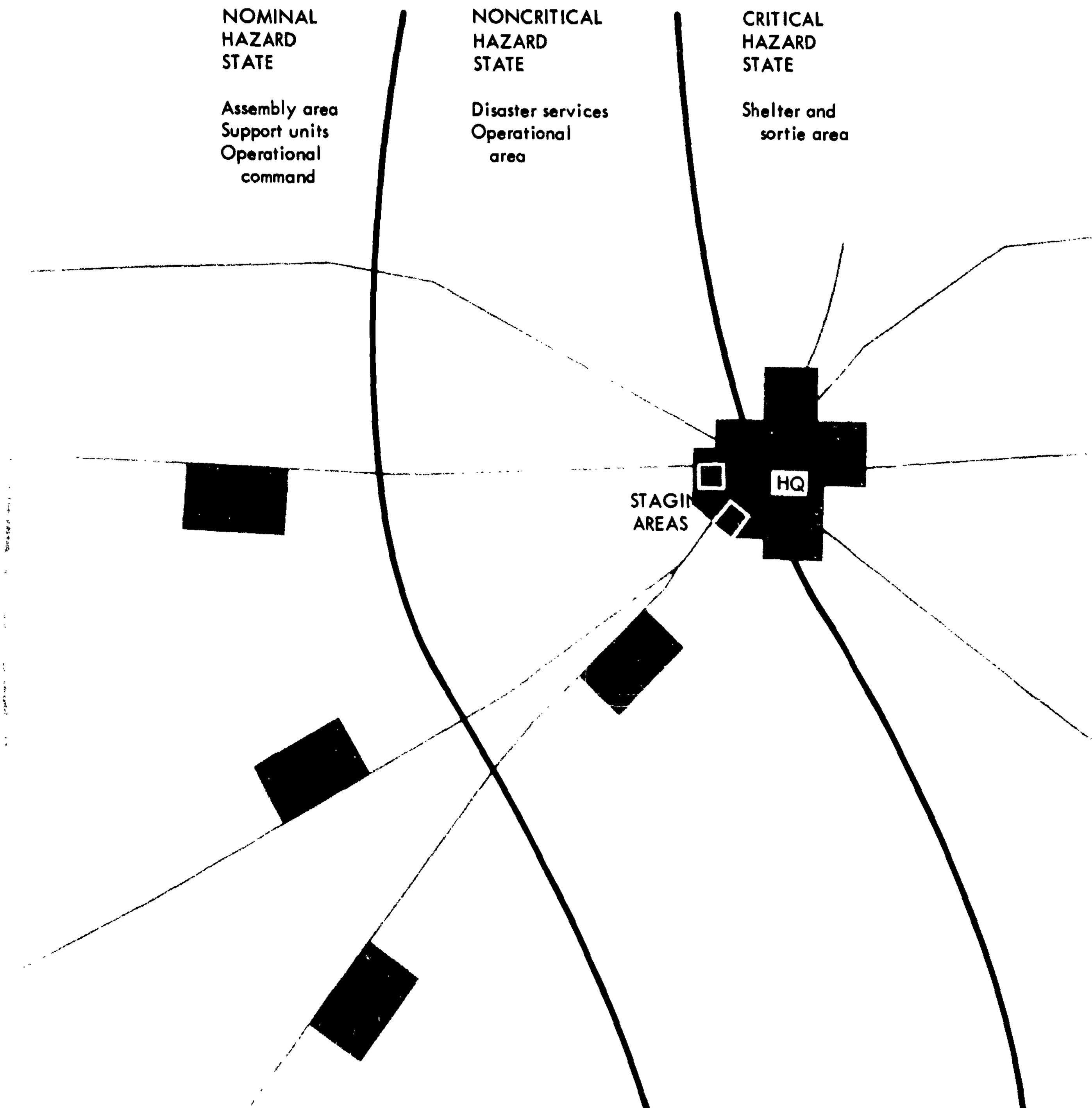
Data taken locally during and immediately after the fallout event should help Operational Command to structure the hazard situation and to relate the available resources to the problem. For this purpose the field readings for Local Command should be sufficiently detailed so that the local areas where outside readings indicate the presence of critical, noncritical, and nominal hazard states could be determined.* This requirement implies the necessity of determining the boundaries between the hazard states (i.e., one or two boundaries for the local region). An example of these boundaries and the relationship of the Operational Command and civil defense forces with respect to these contours is illustrated in Figure 9.

In general, civil defense units would operate in regions with a hazard state not greater than noncritical. Regions exhibiting the critical hazard state would generally employ the shelter countermeasure with occasional sorties by civil defense units and population groups to be made in conditions of extreme urgency. Initially, operational headquarters might of course be in any hazard state. Whenever possible during Phase I or II, the operational headquarters, together with various support units and assembly areas, should be established in regions of lower hazard--preferably a nominal hazard state close to the scene of action if such a state exists or can be produced by decontamination. The radiation field at early times after the cessation of fallout could be characterized well enough for these purposes with a very small number of dose rate readings. The order of 10 to 30 fixed measurement points distributed more or less uniformly over the area of interest should be sufficient.

Accurate information on the status of people in shelters could not be determined by any number of exterior readings due to the wide variability of shelter designs and the errors in techniques used for estimating shielding

* An area, particularly in a city, might exhibit more than one hazard state due to irregularities in the field. Generally, it would be prudent to associate the area with the highest hazard state noted in the area.

Figure 9
REPRESENTATION OF HAZARD STATES IN LOCAL AREAS



characteristics.[11] An approximate determination of hazard states would be possible on the basis of knowledge of the exterior hazard states plus shelter protection factors, but an accurate determination would require interior radiation measurements from individual shelters.

Information requirements for efficient action in the initial recovery phase would have to be much more complex. Determination of requirements and assignment of missions to operational units presupposes a complete understanding of the problems of radiological recovery planning[7] and correspondingly complete information of the postattack situation with respect to both radiological and nonradiological conditions. Generally a factor of 2 or 3 in the variation of the initial radiological conditions assumed in planning can make a considerable difference in the length of the scheduled recovery period, forces required, and possibly methods employed.[7] Consequently, a representation of the situation in terms of fallout contours would not be adequate for planning since conditions predicted on the basis of contours could be in error by a factor of 2 or more.

Planning should be based on radiation measurements at and around the specific areas to be recovered. A measurement accuracy of about ±50 percent would be desirable as shown previously. Measurements of this type might best be accomplished by mobile land monitoring techniques in areas exhibiting noncritical or lower hazard states. To plan the recovery of areas in critical or higher hazard states would be desirable. To accomplish this, fixed monitoring stations should be established at selected points of interest, such as staging areas and utilities, and local aerial monitoring should be initiated under the control of Operational Command.

The feasibility of evacuation might be determined in the latter part of the attack and shelter phase and the initial recovery phase by knowledge of the hazard states in the vicinity of the shelters. Detailed calculation of doses would be useless for this purpose due to the sizable irregularities in dose-rate gradients along evacuation routes, variations in starting points, and walking rates, and similar factors.

Civil Defense Units

The general functions of civil defense operational units--rescue, firefighting, decontamination, and the like--include the following:

1. Assemble at predesignated location (Phases I and II)

2. Determine status of personnel and equipment in the unit and report to Operational Command (Phases I and II)

3. Gain access to hazardous areas as required by mission (Phases I and II)

4. Determine feasibility and detailed approach to accomplishing mission (all phases)

5. Instruct and aid population groups as necessary (Phases I and II)

Determination of status is a vital input from operational units to Operational Command in the attack and shelter phase and the initial recovery phase. These data provide a partial basis on which command can assess its ability to meet the disaster situation and on which it can make appropriate detailed unit assignments. Required status information would include the following radiological and nonradiological information:

1. Total personnel on hand.

2. Total personnel unaccounted for.

3. Total personnel on hand with doses greater than 50, 100, 200 roentgens, respectively.

4. Hazard state in vicinity of assembly area.

5. Status of transportation equipment--capacity, fuel, and state of repair.

6. Status of special countermeasure equipment, e.g., radiacs, motor graders, and water pumps and hoses.

7. Other factors affecting ability to carry out a mission.

To make an accurate status report, every member of the civil defense units must have a tactical dosimeter (nonself reading) and most assembly areas should have dosimeter readers. Tactical dosimeters must be assigned and distributed to personnel of the civil defense units in the preattack period, so that their total dose prior to assembly of the unit in the late attack and shelter phase can be determined. Since this information is primarily for use in determining the status of the unit, there is no compelling requirement that the instruments be self reading. Because the instruments would be in service continuously, simplicity of operation and low maintenance are primary considerations. A radiophotoluminescent device, such as the DT-60/PD personnel dosimeter is typical of this class of instruments. One or more dose-rate meters capable of reading intensities up to the critical hazard state are necessary to determine the hazard state at the assembly area and during access to the damaged area.

One or more dose-rate meters and self-reading dosimeters would be required during accomplishment of the mission as a means of (1) hazard control in both radiological and nonradiological countermeasures and (2) operations control for radiological countermeasures.* Since the objective of the radiological countermeasures in the initial recovery phase is to bring down the hazards to the nominal state, a requirement for reading intensity to 0.1 r/hr is established.** Reading requirements at later times and at all times outside fallout areas would remain at peacetime hazard levels.

Population Groups

The general functions of population groups as part of the civil defense functional organization are:

1. Determination of status of population groups in shelters and elsewhere (Phases I and II)
2. Report of radiological hazard and group status (Phases I and II)
3. Group control (Phases I and II)
4. Self-help actions (Phases I and II)
5. Aid to operational units as required (Phases I and II)
6. Maintenance of civil defense regulations (all phases)

Determination of the status of population groups in fallout areas is clearly an important input into decisions made by the Operational Command in the first two phases. As with civil defense units, these status reports should contain information on all hazard and not be restricted to radiological hazards alone. Status information of interest to Operational Command includes:

1. Number of people in the group or shelter.
2. Number and identification of personnel previously assigned to civil defense units.

---

* One dose-rate meter and two self-reading dosimeters for each independently operating section of a civil defense unit.

** NCRP indicates a normal dose to be less than 3 r/day in heavy fallout regions as a reasonable upper limit to people previously exposed.

3. Number of people injured, both physical and radiological effects.

4. Radiological hazard conditions in the group location.

5. Self-help capabilities, status of equipment.

The measurement requirements for the population group are determined primarily by information needs in the group location rather than by any Operational Command requirements for measurements in other locations. Dose-rate measurements in the group location, such as shelters, should be for the primary purpose of determining the hazard state. Little practical purpose is served by attempting to measure states higher than the critical state inside sheltered locations; consequently, an upper range limitation of about 50 r/hr can be placed on instruments used for this purpose.

Within the range of biological effects included in one state, the population group in a sheltered area might generally be considered as a homogeneous exposure group so that a single measurement of dose or dose rate could be applied to the entire group while its members remain together. A requirement for a minimum of two self-reading dosimeters with a maximum range to at least 200 r would permit dose estimation in the sheltered location and hazard sharing among group members selected for sorties outside the shelter. The same dose-rate range limitation would be appropriate for sorties since such actions would be limited to outside conditions exhibiting a critical hazard state or lower. The requirement for sorties also suggests a minimum of two dose-rate meters for each population group. One is kept in the shelter at all times, and at least one is assigned to the sortie group.

It would not appear desirable for Operational Command to use measurements taken immediately outside shelters as a basis for estimating the characteristics of the fallout distribution. Shelters in urban areas are generally correlated with the heavily built-up regions. Due to variations in radiation readings induced by the irregularities in fallout deposition and by shielding and other variables in built-up regions, the measurements in the vicinity of most shelters might be quite difficult to interpret in terms of dose-rate contours. Selective use of such readings, however, might form part of the system for determining the gross fallout pattern. Outside readings could be used from those shelters located in large open, unpaved areas. For these reasons, there would be no requirement for high-range dose-rate meters above 50 r/hr inside most shelters. Remote reading high-scale meters in the range of 50 to 1,000 r/hr or higher would be required for selected shelters and other stations making outside measurements which form part of the monitoring network for Operational Command.

IV FIXED RADIOLOGICAL MONITORING SYSTEMS TO SUPPORT ADMINISTRATIVE COMMAND

Administrative Command must have summary radiological information on a nationwide basis in the early attack and shelter phase to provide warning and for general assessment of the condition of the nation. Such data are required to support both civil and military functions of Administrative Command. This section develops the design parameters and operational procedures of monitoring systems to provide the data. The following criteria were evolved:

1. Fixed monitoring stations are indicated.
2. Spacings between stations are dependent on the characteristics of the fallout field and the distribution of resources which sould be monitored.
3. Station reporting procedures should be coordinated with hazard-state thresholds.

The design of radiological monitoring systems to support Administrative Command must be carried out in relation to its information requirements which stem directly from its function. Administrative Command, as noted earlier, must establish a broad policy and the over-all objectives for the recovery of the nation and the continuing military efforts. The actual execution of this function will change over time during a nuclear war and the subsequent recovery periods, and radiological information requirements will change correspondingly.

Basically, because the sphere of operation of Administrative Command includes the entire nation, it must utilize information which is essentially summary in nature. The nation is simply too large and the operational situation too complex to permit use of detailed data except in certain unique situations. Administrative Command clearly should have the ability, for example, to determine the advisability of the population to move from one state or region to another; however, it could not be expected to have the ability to specify which railroad track or highway to use in carrying out the remedial evacuation. In general, Administrative Command can acquire radiological or any other information by (1) operating an independent monitoring system of its own and (2) acquiring information through the chain of command--forwarded and summarized from one echelon to the next. In view of the time scale in which events can be expected to occur in a civil defense emergency and the speed at which information should be acquired, both systems appear to be necessary although they should be utilized at different phases in the recovery operations.

During the attack and shelter phase of the war, Administrative Command requires radiological information to provide warning to Operational Command and for general assessment of the condition of the nation in terms of gross hazard states and casualties. The magnitude of casualties in the civil population and of damage to industry would play a vital role in military decisions concerning the prosecution of the war. Consequently, assessments of these must be made available to the President and the national military commands at the earliest possible time. The general emphasis of the assessment must be directed toward determining the effectiveness with which the nation can support the necessary military operations to conclude the war and the most effective broad procedures by which the nation can initiate recovery operations. Early radiological information is of a premium, and accuracy of assessment must probably be sacrificed for speed.

During the initial recovery phase and subsequent periods, on the other hand, information to support Administrative Command is characterized by status reports. These would be provided by lower echelons through the chain of command and would include information on the casualties and fatalities from all hazards, the quantity and condition of resources, and the operational status of manufacturing and transportation facilities. Little, if any, raw radiological information would be required.

To ensure that Administrative Command will have the capability of carrying out early assessments of the radiological hazard situation in the nation, a fixed monitoring system seems to be indicated. The choice between an automatic or a manual system does not appear to be critical in the matter of fulfilling information requirements for Administrative Command, except for certain considerations of speed in reporting. Manual systems have the inescapable advantage of flexibility provided by the people in the system. Moreover, manual monitoring stations for the most part can be simpler in design and therefore require less maintenance and routine testing than an automatic monitoring point. However, a manual monitoring system requires shielded monitoring stations and a training program for monitoring personnel and includes, of necessity, a calculated risk that monitoring personnel will remain at their stations and function properly under emergency conditions. Aside from these differences, the same constraints can govern the design of both automatic and manual fixed monitoring systems to support Administrative Command.

Location Pattern of Monitoring Points

Radiological information and all other necessary command intelligence must be handled at Administrative Command headquarters in terms of summaries and large aggregations of material. Each class of data normally is summarized in a form best suited to its individual characteristic, although modified by its relationship to other classes of information with which it must be used by Administrative Command in planning and decision processes. The detail of

radiological information which a fixed monitoring system should provide to Administrative Command can, in general, be determined as a function of the use of the information. The required quantity and detail of the necessary information strongly controls the locational pattern of the monitoring points.

Fixed-point monitoring information is generally used to provide the earliest possible assessment of the radiological hazard situation throughout the nation and to estimate the number of casualties or the population at risk as a result of fallout. In the early time period, these operations must of necessity be gross. Division of the nation into areas characterized in terms of hazard states or similar relatively broad classes appears to be suitable in the early period. If necessary, subsequent refinement will be possible upon receipt of more detailed information from Operational Command or other monitoring systems. The location of fixed monitoring stations on a national basis should be of sufficient density to permit this operation to be carried out.

The estimation of fallout casualties throughout the nation requires, in addition to radiological information, data describing the location and the degree of fallout protection of the population. At Administrative Command headquarters the known detail of these data is obviously limited. For example, Administrative Command will probably have only the most general idea of the number and location of people who were able to take refuge in Class A shelters versus how many were caught in their homes with a Class E protection factor. Administrative Command can know in advance the location and capacity of each shelter in each category of protection, but there appears to be no way in the early time period to acquire an accurate census of the shelter population. In view of this situation, the location pattern of the monitoring stations should be devised to provide only a gross indication of the radiation existing in an area. To define the radiological situation in more detail than the known pattern and protection factors of the population in the area would serve no useful purpose.

Obviously, these early analyses and the operational decisions based upon them will not be altogether accurate. However, in the early attack and shelter phase, detail and accuracy likely must be sacrificed for speed. The pace at which Administrative Command carries out its early functions should be essentially the same as that of the national military command. The character of military decisions will depend in part upon the status of the nation. Consequently, status reports should be prepared at least as rapidly as the military situation demands.

The location pattern and station spacing of a fixed monitoring system therefore can be established within the constraints of two basic considerations. First, the spacing should be small with respect to the fallout pattern and the rate and character with which the areas and items of interest change in both time and space. This general specification is, of course, not unlike that applicable to any system of physical measurement and analysis. Second, the spacing should be small with

respect to the total area over which command has responsibility and the capability of utilizing and combining the radiological information with other command information to carry out its decision process.

Hazard-State Variations in Fallout Patterns

At Administrative Command, during the early time period following an attack, characterization of the radiological situation throughout the nation in terms of the hazard states from whole-body gamma radiation appears to be suitable. Thus, a basic guide can be developed for the spacing of monitoring stations from the manner in which the hazard states vary within a fallout field. These hazard states, as noted in Section III, can be defined in a number of ways. For purposes here, they have been identified in terms of whole-body dose as follows:

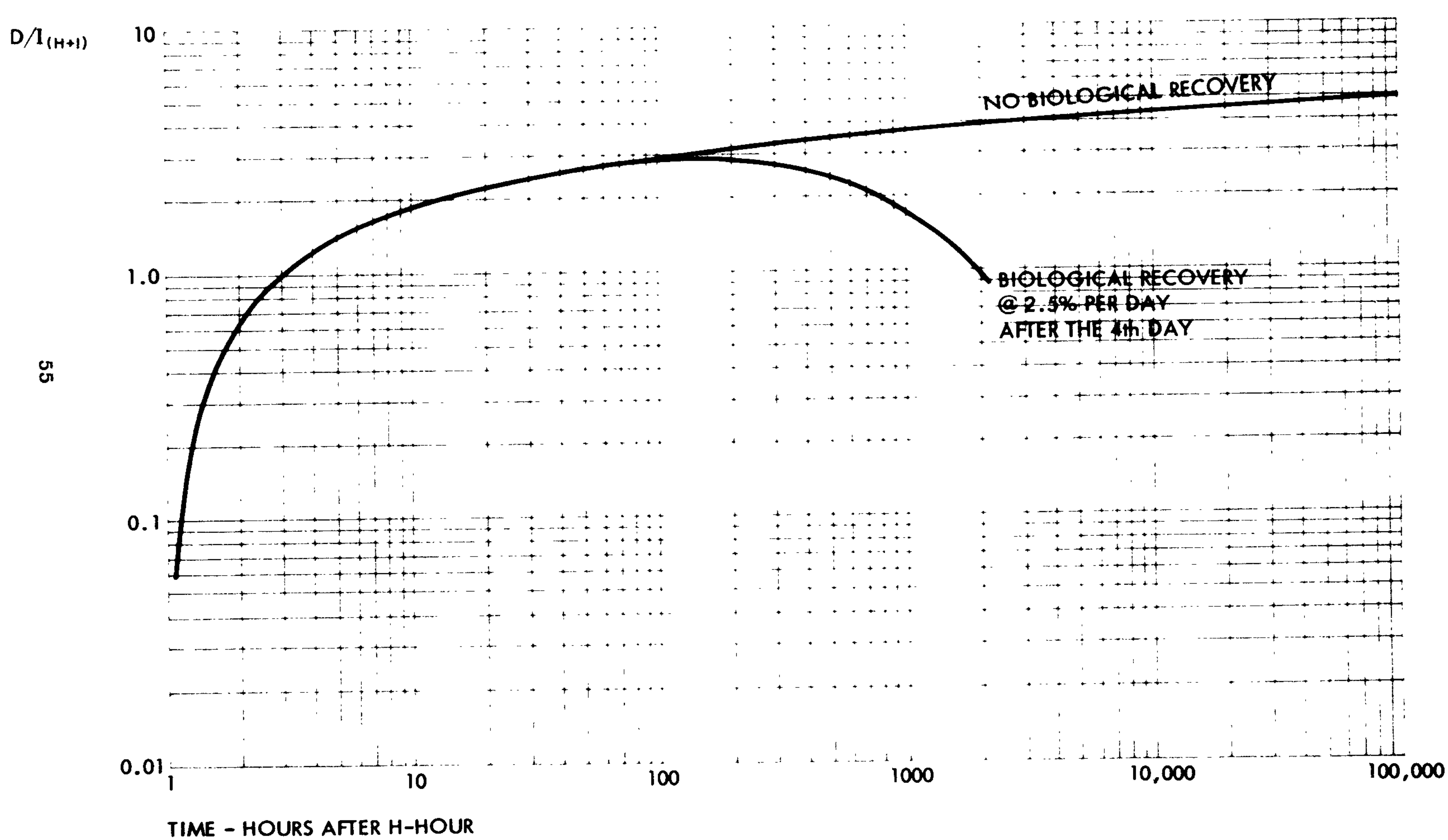
Hazard State	Dose Range (roentgens)
Peacetime	0-12
Nominal	12-50
Noncritical	50-200
Critical	200-1,000
Extreme	> 1,000

The peacetime hazard state bounded by doses of 0-12 roentgens is of primary importance in areas not contaminated by fallout. Since no operationally significant difference in biological response exists between doses of 0-12 and 12-50 roentgens, these are lumped together in determining the hazard-state variation within a fallout pattern.

For the purposes of the design of a fixed monitoring system, however, these doses defining the range of the hazard states or injury classes must be related to radiation intensities--the phenomena which the system actually measures. All dose-intensity relationships of necessity involve the factor of time. The techniques of estimating the dose received in a fallout field as a function of time are well known. Use of these procedures permits the calculation of dose received at a point for any time in the future, if the intensity, decay rate, biological recovery rate, and stay time in the contaminated area are known.

This dose-intensity relationship as a function of stay time is summarized in Figure 10 for standardized intensity values corrected to H+1 hours with an exponential decay of $t^{-1.2}$. The accumulated dose, both with and without biological recovery, is shown with the recovery beginning at the end of the fourth day following initial exposure. The recovery rate is taken as 2.5 percent per day with an irrecoverable portion limited to 10 percent of the gross dose. Clearly, because of the diverse factors affecting dose, the hazard state limits must be defined in terms of all these parameters, especially in the early time periods when the dose is being accumulated at a very high rate. This relationship for

Figure 10
RELATIONSHIP OF DOSE TO DOSE RATE WITH TIME



four typical stay times, excluding biological recovery as a function of the H+1 value of intensity, is shown in Table XI.

Thus, for example, for a stay time of four days any point with an H+1 intensity reading of less than 18 roentgens per hour would receive a dose not greater than 50 roentgens, while areas with H+1 intensities less than 72 roentgens per hour would receive doses less than 200 roentgens in the same time period. Stay times of greater length, such as two weeks, clearly reduce the permissible value of the H+1 intensity to produce the same dose or injury class.

Table XI

STANDARD H+1 DOSE RATES TO INDUCE HAZARD-STATE DOSE LIMITS FOR SELECTED STAY TIMES

	H+1 Intensity, r/hr		
Stay Time	50 r	200 r	1,000 r
1 day	22	88	435
4 days	18	72	357
1 week	17	67	333
2 weeks	13	52	263

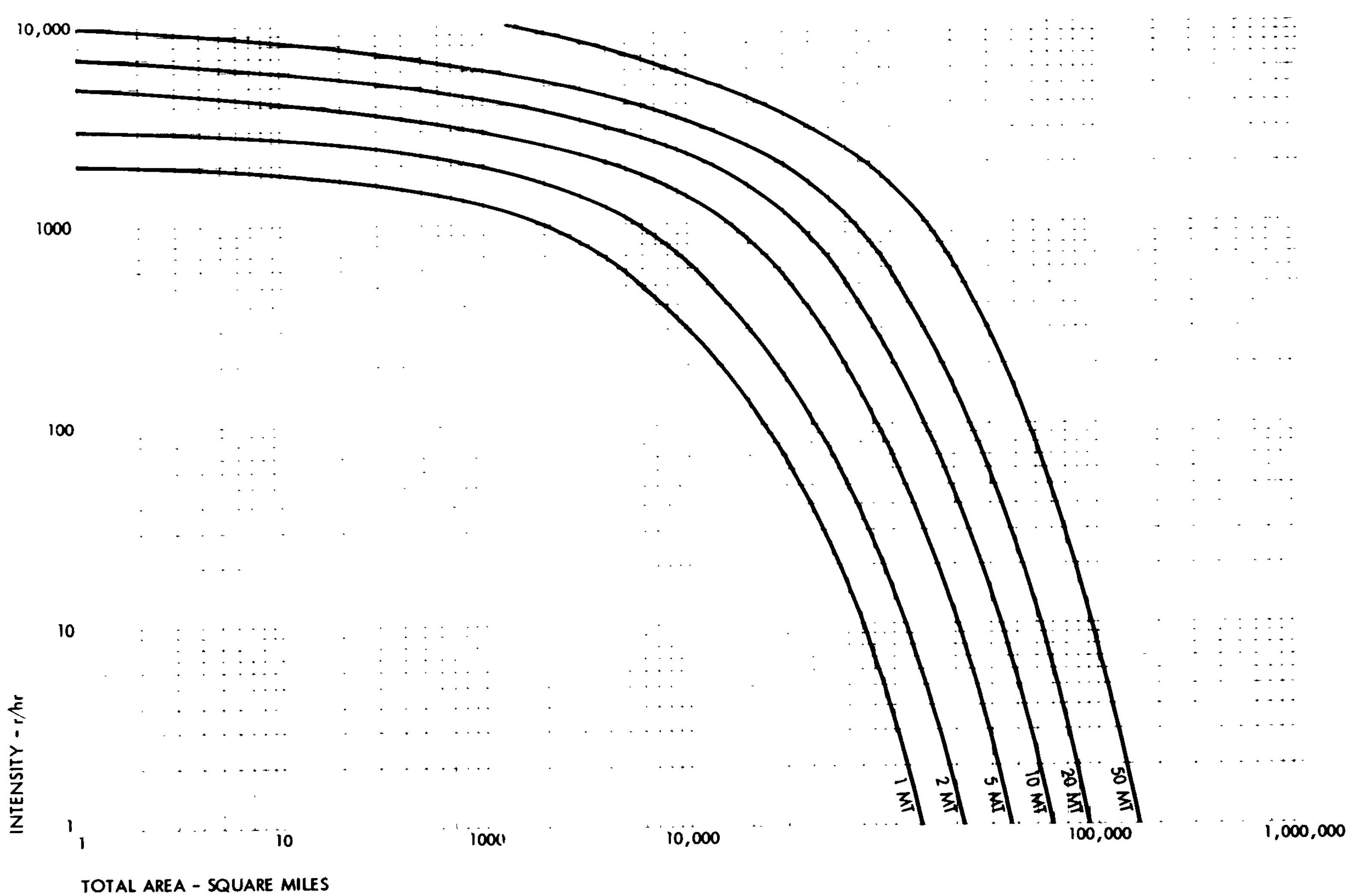
By use of the relationships in Table XI, the areas of a fallout pattern which induce each hazard state can be defined. While the shape and over-all configuration of a fallout pattern varies with winds and other forces of nature, the area included within a given intensity contour is essentially a function of the yield and fission ratio of the weapon. For example, the area within the 100 roentgen contour for a 10 MT weapon of 100 percent fission is estimated to be about 14,300 square miles for a 20-mile per hour wind and about 15,400 square miles for a 30 mile per hour wind, a difference of less than 10 percent.* For planning purposes differences of this magnitude should not be significant.

Figure 11 illustrates the relationship between the intensity contours and the areas they enclose for weapons of 1, 2, 5, 10, 20, and 50 MT. The general shape of each curve is essentially the same, although the areas enclosed within a contour vary widely with the various weapon yields. For all weapons the reduction in area versus intensity shows a relatively linear relationship for all weapons in the lower intensity regions. An abrupt break point is reached at about the 1,000 roentgen per hour contour, where the areas rapidly decrease to the vanishing point.

With the use of these area-intensity relationships a conversion can be made to hazard states existing in a fallout pattern as a function of the intensities for stay times shown on Table XI. The cumulative areas within the pattern

*All computations of fallout pattern dimensions are based upon. C.F. Miller, Fallout and Radiological Countermeasures,[10] Volume I, Stanford Research Institute, February 1963.

Figure 11
AREAS ENCLOSED BY ISOINTENSITY CONTOURS IN FALLOUT PATTERNS FROM SINGLE WEAPONS



attributable to the four hazard states as extracted from Figure 11 are shown in Table XII for the four stay times and four hazard states. For purposes of these calculations the one roentgen per hour contour is assumed to bound the pattern. Thus, for example, in a fallout pattern from a 5 MT weapon the total area of the pattern is 38,000 square miles and accounts for all hazard states; for a stay time of four days the intensity threshold of the noncritical hazard state is 18 roentgens at H+1. This contour encloses 17,100 square miles and includes the noncritical and all successively serious hazard states as well. These cumulative areas are shown in Table XIII in terms of percentage of area of a fallout pattern covered by these hazard states. From these cumulative descriptions of the hazard state the incremental variations of a pattern, in terms of the area occupied by each hazard state, can be derived. Table XIV indicates the area in square miles occupied by each hazard state for patterns from several weapon yields, and Table XV provides a comparison of these areas in terms of percentage of the total area.

In general, the percentage of a fallout pattern occupied by each hazard state remains substantially the same for all weapon yields. The area of the nominal hazard state for a four-day stay time varies from 57 percent for a 1 MT weapon to 49.7 percent for a 50 MT weapon. For all except the larger weapons the nominal hazard-state area is essentially 50 percent of the total pattern. The variation of the area of the noncritical hazard state generally is less with the difference in the range of 4 percent while for the critical hazard state the proportion of the total pattern is relatively constant in the order of 15 percent of the total.

The spread in the percentage of the fallout pattern covered by the extreme hazard state is somewhat greater than for the lesser hazard states. The variation is in the order of 10 percent from the smallest to the largest weapons considered.

In general, the portion of the pattern occupied by each hazard state decreases as the seriousness of the hazard increases. The typical trend in this relationship is shown in Figure 12, for the 1, 5, and 10 MT weapons. Typically, the area of nominal hazard covers about 50 percent of the total pattern, with the successively increasing hazard states occupying about 20, 16, and 10 percent, respectively. However, somewhat of a reversal in the trend is apparent for the 50 MT weapon in the extreme hazard state; the portion of the fallout pattern in the critical hazard state is slightly less than the area of the extreme hazard state.

These data shown above also illustrate clearly that the manner in which the hazard state is defined in terms of stay time does not significantly change the relationship of the areas of a fallout pattern with respect to the hazard states. For each weapon the variation in area between a stay time of one day and two weeks is typically in the order of 2 to 4 percent for all but the extreme

Table XII

CUMULATIVE AREAS IN AN IDEALIZED SINGLE-WEAPON FALLOUT PATTERN DERIVED FROM SELECTED WEAPON YIELDS (Square Miles)

Hazard State	Fallout Pattern Areas from Weapon Yields of:					
	1 MT	2 MT	5 MT	10 MT	20 MT	50 MT
			1-Day Stay Time			
Extreme	700	1,450	3,400	6,700	12,000	24,500
Critical	2,600	4,600	9,000	15,400	26,000	48,000
Noncritical	5,300	8,800	16,000	26,000	42,000	76,000
Nominal	13,500	21,500	38,000	59,000	91,000	159,000
			4-Day Stay Time			
Extreme	860	1,800	4,000	7,600	13,500	27,500
Critical	2,900	5,100	10,000	17,000	28,000	52,000
Noncritical	5,800	9,400	17,100	28,000	45,000	80,000
Nominal	13,500	21,500	38,000	59,000	91,000	159,000
			1-Week Stay Time			
Extreme	920	1,850	4,200	8,000	14,000	28,000
Critical	3,000	5,200	10,400	17,400	29,000	54,000
Noncritical	5,900	9,700	17,900	28,400	46,000	82,000
Nominal	13,500	21,500	38,000	59,000	91,000	159,000
			2-Week Stay Time			
Extreme	1,150	2,300	5,000	9,000	15,800	32,000
Critical	3,500	5,900	11,400	19,000	31,300	58,000
Noncritical	6,400	10,400	19,000	30,000	48,500	88,000
Nominal	13,500	21,500	38,000	59,000	91,000	159,000

Source: Derived by Stanford Research Institute

Table XIII

CUMULATIVE PERCENTAGE OF TOTAL AREA IN AN IDEALIZED SINGLE-WEAPON FALLOUT PATTERN DERIVED FROM SELECTED WEAPON YIELDS

Hazard State	Fallout Pattern Area Percentage from Weapon Yields of:					
	1 MT	2 MT	5 MT	10 MT	20 MT	50 MT
			1-Day Stay Time			
Extreme	5.2%	6.7%	8.9%	11.4%	13.2%	15.4%
Critical	19.3	21.4	23.7	26.1	28.6	30.2
Noncritical	39.2	40.9	42.2	44.1	46.2	47.8
Nominal	100.0	100.0	100.0	100.0	100.0	100.0
			4-Day Stay Time			
Extreme	6.4	8.4	10.5	12.9	14.9	17.3
Critical	21.5	23.7	26.3	28.8	30.7	32.7
Noncritical	42.9	43.7	45.0	47.5	49.4	50.4
Nominal	100.0	100.0	100.0	100.0	100.0	100.0
			1-Week Stay Time			
Extreme	6.8	8.6	11.1	13.6	15.4	17.6
Critical	22.2	24.2	27.4	29.5	31.9	34.0
Noncritical	43.7	45.1	47.2	48.1	50.6	51.6
Nominal	100.0	100.0	100.0	100.0	100.0	100.0
			2-Week Stay Time			
Extreme	8.5	10.7	13.2	15.3	17.4	20.1
Critical	25.9	27.4	30.0	32.2	34.4	36.5
Noncritical	47.4	48.4	50.0	50.9	53.3	55.4
Nominal	100.0	100.0	100.0	100.0	100.0	100.0

Source: Derived by Stanford Research Institute

Table XIV

INCREMENTAL AREAS IN AN IDEALIZED SINGLE-WEAPON FALLOUT PATTERN DERIVED FROM SELECTED WEAPON YIELDS (Square Miles)

Hazard State	Fallout Pattern Areas from Weapon Yields of:					
	1 MT	2 MT	5 MT	10 MT	20 MT	50 MT
			1-Day Stay Time			
Extreme	700	1,450	3,400	6,700	12,000	24,500
Critical	1,900	3,150	5,600	8,700	14,000	23,500
Noncritical	2,700	4,200	7,000	10,600	16,000	28,000
Nominal	8,200	12,700	22,000	33,000	49,000	83,000
			4-Day Stay Time			
Extreme	860	1,800	4,000	7,600	13,500	27,500
Critical	2,040	3,300	6,000	9,400	14,500	24,500
Noncritical	2,900	4,300	7,100	11,000	17,000	28,000
Nominal	7,700	12,100	20,900	31,000	46,000	79,000
			1-Week Stay Time			
Extreme	920	1,850	4,200	8,000	14,000	28,000
Critical	2,080	3,350	6,200	9,400	15,000	26,000
Noncritical	2,900	4,500	7,500	11,000	12,000	28,000
Nominal	7,600	11,800	20,100	30,600	45,000	77,000
			2-Week Stay Time			
Extreme	1,150	2,300	5,000	9,000	15,800	32,000
Critical	2,350	3,600	6,400	10,000	15,500	26,000
Noncritical	2,900	4,500	7,600	11,000	17,200	30,000
Nominal	7,100	11,100	19,000	29,000	42,500	71,000

Source: Derived by Stanford Research Institute

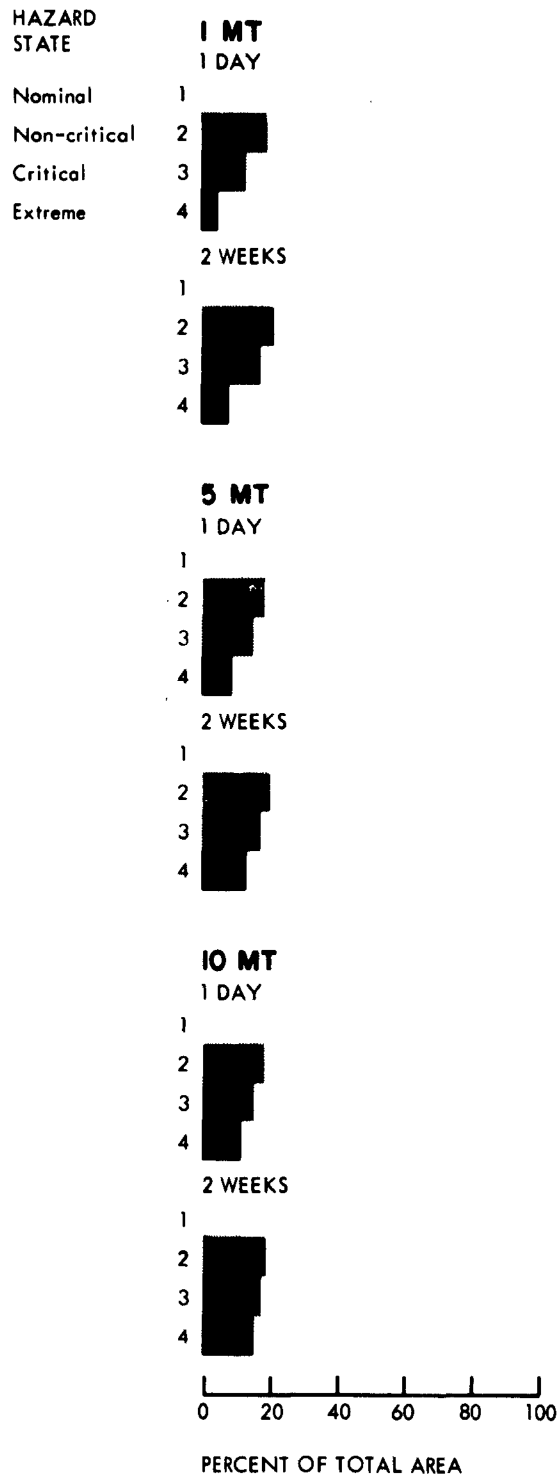
Table XV

PERCENTAGE OF TOTAL AREA IN AN IDEALIZED SINGLE-WEAPON FALLOUT PATTERN DERIVED FROM SELECTED WEAPON YIELDS

Hazard State	Fallout Pattern Area Percentage from Weapon Yields of:					
	1 MT	2 MT	5 MT	10 MT	20 MT	50 MT
			1-Day Stay Time			
Extreme	5.2%	6.7%	8.9%	11.4%	13.2%	15.4%
Critical	14.1	14.7	14.7	14.7	15.4	14.8
Noncritical	20.0	19.5	18.5	18.0	17.6	17.6
Nominal	60.7	59.1	57.9	55.9	53.8	52.2
			4-Day Stay Time			
Extreme	6.4	8.4	10.5	12.9	14.8	17.3
Critical	15.1	15.3	15.8	15.9	15.9	15.4
Noncritical	21.5	20.0	18.7	18.6	18.7	17.6
Nominal	57.0	56.3	55.0	52.6	50.6	49.7
			1-Week Stay Time			
Extreme	6.8	8.6	11.1	13.6	15.4	17.6
Critical	15.4	15.6	16.3	15.9	16.5	16.4
Noncritical	21.5	20.9	19.7	18.6	18.7	17.6
Nominal	56.3	54.9	52.9	51.9	49.4	48.4
			2-Week Stay Time			
Extreme	8.5	10.8	13.2	15.3	17.3	20.0
Critical	17.4	16.7	16.8	16.9	17.0	16.4
Noncritical	21.5	20.9	20.0	18.6	18.9	18.9
Nominal	52.6	51.6	50.0	49.2	46.8	44.7

Source: Derived by Stanford Research Institute

Figure 12
PERCENT OF TOTAL AREA OF AN IDEALIZED SINGLE WEAPON FALLOUT PATTERN FROM 1, 5, AND 10 MT WEAPONS ATTRIBUTABLE TO FOUR HAZARD STATES



hazard state. Variations of 6 to 7 percent appear to more accurately typify this hazard state.

It is readily apparent from these data that the general characteristics of the pattern which a fixed monitoring system must define are relatively gross. The areas of interest are measured in terms of thousands of square miles for most situations and the changes in hazard states as a function of distance is relatively slow. These characteristics clearly ease the burden on the design of the monitoring system. The spacing of monitoring stations can be made commensurate with the pattern characteristics. In order for a fixed monitoring system to detect and define the hazard areas, the stations must lie within these areas. Because the location and configuration of fallout patterns obviously cannot be predicted, the spacing of the monitoring stations across the nation must be of sufficient density so that a reasonable expectation of detecting at least the critical hazard state can be obtained. Naturally, the greater the number of stations lying within a pattern, the greater will be the accuracy to which the pattern can be defined.

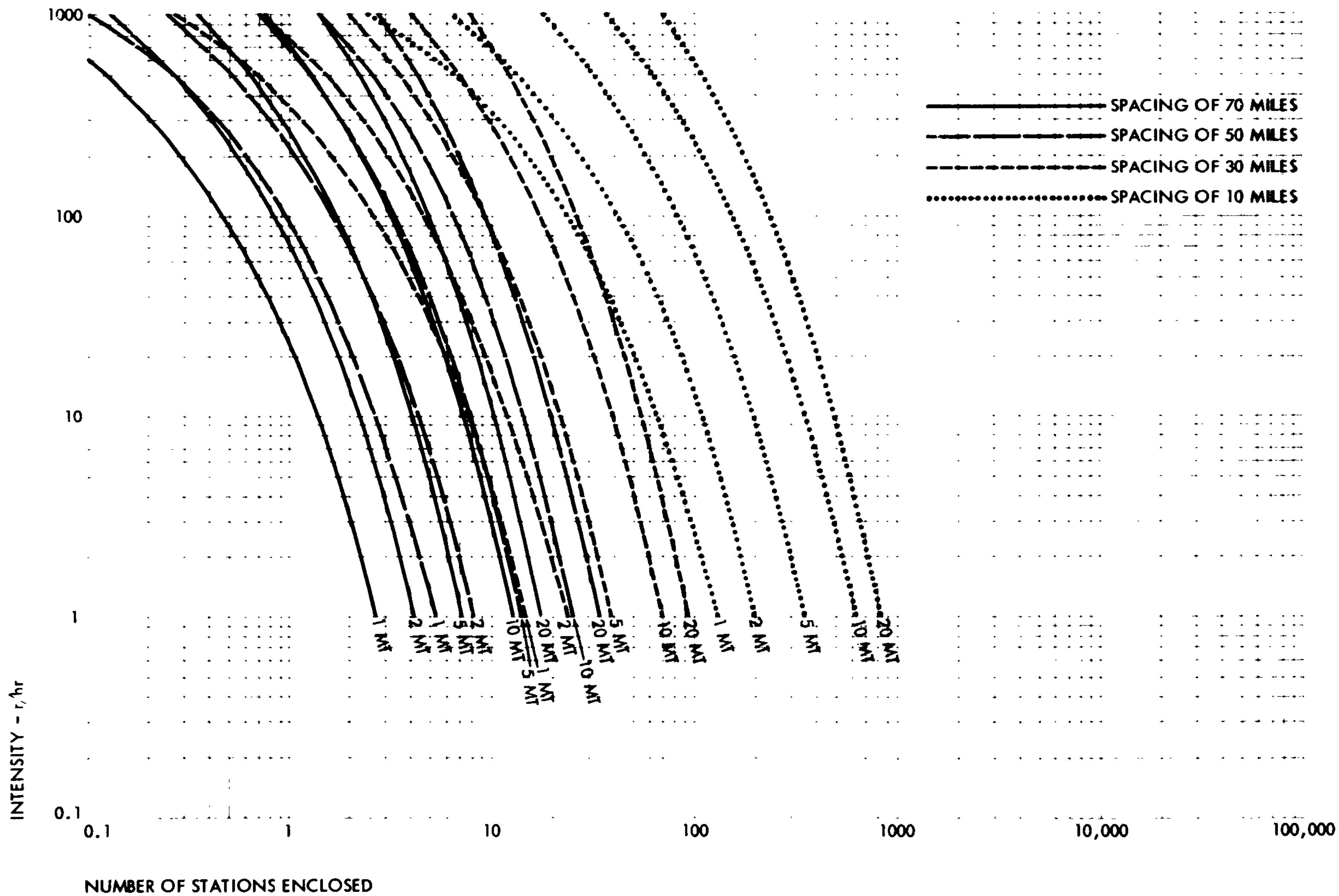
Station Spacing for Hazard-State Detection

To develop measures of the relationship between station spacing and the number of stations expected to detect each hazard state, monitoring points placed on a rectangular grid at four different spacings were studied. These spacings were:

Station Spacing (miles)	Area per Station (sq.miles)
10	100
30	900
50	2,500
70	4,900

With these grid spacings, the expected number of monitoring stations within each hazard state of a pattern were determined with the assumption being made that the fallout pattern was unpredictable in all respects except their areas. Yields of 1, 2, 5, 10, and 20 MT were considered. The generalized results of these calculations are shown in Figure 13, with the expected cumulative number of stations enclosed in successive radiation intensity contours for station spacings of 10, 30, 50, and 70 miles. Figure 13 permits the estimation of the number of stations enclosed within any intensity contour if other hazard-state definitions with different dose limits are desired. The expected number of stations to be enclosed within a total pattern, or parts thereof, have extremely wide limits as a function of both spacing and yield. Because the maximum limit of the extreme

Figure 13
EXPECTED CUMULATIVE NUMBER OF STATIONS ENCLOSED WITHIN ISOINTENSITY CONTOURS FOR SELECTED WEAPONS



hazard state has been established here as 435 roentgens per hour, the calculations were limited to 1,000 roentgens per hour. Moreover, as can be inferred from Figure 11, the expected number of stations in the pattern above the 1,000 roentgen per hour contour rapidly approaches the vanishing point.

To illustrate the trend in more detail, representative data have been extracted from Figure 13 and are shown in Table XVI for a stay time of one day and in Table XVII for a stay time of one week. Both tables illustrate the number of monitoring points which could be expected to detect each hazard state when the points are spaced at 10, 30, 50, and 70 miles. These data, rounded to the nearest whole number of stations, are shown for weapon yields of 1, 2, 5, 10, and 20 MT.

Because the area monitored per station varies as a function of the square of the spacing, the expected number of stations detecting a given hazard state varies in the same progression. For a 5-megaton weapon, for example, the number of stations expected in the noncritical hazard state decreases from 70 in a 10-mile array to 8 when the spacing is increased to merely 30 miles. Within any one grid spacing the expected number of stations to detect and differentiate one hazard state from another is directly related to the area within each hazard state. In general, no method apparently exists by which the more severe hazard states can be detected in relation to the lesser hazard states for any weapon because (1) the relationship is essentially fixed among the hazard states and the areas they cover within each fallout pattern, and (2) the geographical areas which will be affected are completely unpredictable.

A certain error in measurement will be encountered under the operational principle that the hazard state detected by a monitoring station characterizes the entire area attributable to that station. On a 30-mile spacing, for example, detection by a station of a noncritical hazard state is assumed to indicate that this condition exists within the general 900-square mile area associated with the station. A measure of the error which this procedure may typically produce is summarized in Table XVIII for a stay time of one week, for each hazard state, and for five weapon yields. The actual area occupied by each hazard state as predicted from Figure 13 and Table XIV is compared to the area of each hazard state as predicted by the number of stations detecting the hazard state shown in Table XVII. For example, the area of the critical hazard state for a 5-MT weapon is estimated to be 6,200 square miles. As shown in Table XVII, the number of stations expected to detect this state is 62, 7, 2, and 1 for spacings of 10, 30, 50, and 70 miles, respectively. The corresponding areas estimated to be included in the critical hazard state are therefore 6,200, 6,300, 5,000 and 4,900 square miles. If, then, the estimated areas as defined by the monitoring stations are compared to the actual 6,200-square mile area, an indication of both the absolute error and the percentage of error can be derived. These are indicated in Table XVIII.

Table XVI

EXPECTED NUMBER OF MONITORING STATIONS DETECTING HAZARD STATES FROM SELECTED WEAPON YIELDS FOR A STAY TIME OF ONE DAY

Hazard State	1 MT	2 MT	5 MT	10 MT	20 MT
		Monitoring Stations at Weapon Yields of:			
			10-Mile Spacing		
Extreme	7	15	34	67	120
Critical	19	31	56	87	140
Noncritical	27	42	70	106	160
Nominal	82	127	220	330	490
			30-Mile Spacing		
Extreme	1	2	4	7	13
Critical	2	4	6	9	16
Noncritical	3	5	8	12	18
Nominal	10	14	24	37	54
			50-Mile Spacing		
Extreme	0	1	1	2	5
Critical	1	1	2	3	6
Noncritical	1	2	3	4	6
Nominal	3	5	9	13	20
			70-Mile Spacing		
Extreme	0	0	1	1	2
Critical	0	1	1	2	3
Noncritical	1	1	1	2	3
Nominal	2	3	4	7	10

Table XVII

EXPECTED NUMBER OF MONITORING STATIONS DETECTING HAZARD STATES FROM SELECTED WEAPON YIELDS FOR A STAY TIME OF ONE WEEK

	Monitoring Stations at Weapon Yields of:				
Hazard State	1 MT	2 MT	5 MT	10 MT	20 MT
			10-Mile Spacing		
Extreme	9	19	42	80	140
Critical	21	34	62	94	150
Noncritical	29	45	75	110	170
Nominal	76	118	281	306	450
			30-Mile Spacing		
Extreme	1	2	5	9	15
Critical	2	4	7	10	17
Noncritical	3	5	8	12	19
Nominal	8	12	20	36	46
			50-Mile Spacing		
Extreme	0	1	2	3	5
Critical	1	1	2	4	6
Noncritical	1	2	3	4	7
Nominal	3	4	8	12	18
			70-Mile Spacing		
Extreme	0	0	1	2	3
Critical	0	1	1	2	3
Noncritical	1	1	2	2	3
Nominal	2	2	4	6	9

Table XVIII

EXPECTED ERRORS IN HAZARD-STATE INDICATION WITH FOUR MONITOR-STATION GRID SPACINGS

YIELD (MT)	ACTUAL AREA (sq mi)	Estimated Area for Various Grid Spacings (Square miles)				Difference between Actual Area and Monitored Area							
						Square-mile Difference				Percentage Difference			
		10	30	50	70	10	30	50	70	10	30	50	70
EXTREME HAZARD STATE													
1	920	900	900	0	0	-20	-20	-920	-920	-2.2	-2.2	-100	-100
2	1,850	1,900	1,800	2,500	0	+50	-50	+650	-1,850	+2.7	-2.7	+35.2	-100
5	4,200	4,200	4,500	5,000	4,900	0	+300	+800	+700	0	+7.1	+19	+16.7
10	8,000	8,000	8,100	7,500	9,800	0	+100	-500	+1,800	0	+0.1	-6.2	+22.5
20	14,000	14,000	13,500	12,500	14,700	0	-500	-1,500	+700	0	-3.5	-10.7	+5.0
CRITICAL HAZARD STATE													
1	2,080	2,100	1,800	2,500	0	+20	-280	+420	-2,080	+0.9	-13.5	+20.2	-100
2	3,350	3,400	3,600	2,500	4,900	+50	+250	-850	+1,550	+1.4	+7.4	+25.4	+46.3
5	6,200	6,200	6,300	5,000	4,900	0	+100	-1,200	-1,300	0	+1.6	-19.3	-20.9
10	9,400	9,400	9,000	10,000	9,800	0	-400	+600	+400	0	-4.2	+6.3	+4.2
20	15,000	15,000	15,300	15,000	14,700	0	+300	0	-300	0	+2.0	0	-2.0
NONCRITICAL HAZARD STATE													
1	2,900	2,900	2,700	2,500	4,900	0	-200	-400	+2,000	0	-0.6	-1.3	+68.9
2	4,500	4,500	4,500	5,000	4,900	0	0	+500	-400	0	0	+11.1	-8.9
5	7,500	7,500	7,200	7,500	9,800	0	-300	0	-2,300	0	-4.0	0	+30.8
10	11,000	11,000	10,800	10,000	9,800	0	-200	-1,000	-1,200	0	-1.8	-9.0	-10.9
20	17,000	17,000	17,100	17,500	14,700	0	+100	+500	-2,300	0	+0.5	+2.9	-13.5
NOMINAL HAZARD STATE													
1	7,600	7,600	7,200	7,500	9,800	0	-400	-100	+2,200	0	-5.2	-1.3	+29.0
2	11,800	11,800	10,800	10,000	9,800	0	-1,000	-1,800	-2,000	0	-8.4	-15.2	-16.9
5	20,100	20,100	18,000	20,000	19,600	0	-2,100	-100	-500	0	-10.4	-0.4	2.4
10	30,600	30,600	32,400	30,000	29,400	0	+1,800	-600	-1,200	0	+15.8	-1.9	-3.9
20	45,000	45,000	41,400	45,000	44,100	0	-3,600	0	-900	0	-8.0	0	-2.0

As can be noted, the errors are of both signs; that is, in some situations the size of the area for a hazard state is overstated on the basis of monitoring information while for other conditions the area estimated is less than the actual area. Typically, as would be expected, the general accuracy to which each hazard-state area is defined increases with a decreasing distance between stations. The exceedingly high accuracy with which the 10-mile spaced stations determine the pattern configuration must be regarded as spurious, because the areas within a fallout pattern in most cases cannot be calculated to accuracies greater than 100 miles, the area per station.

The spacing requirements for stations of a fixed monitoring system based upon the expected number of stations to detect each hazard-state area are readily apparent from these considerations. In general, the spacing should be such that Administrative Command will have a reasonable expectation that at least the critical hazard state will be detected. If, of course, the area of the extreme hazard state can be identified by the system with little increase in cost or complexity, the effort should be made. Because the area of each hazard state is a function of the weapon yield and its fission ratio, the choice of station spacing to detect these states must of necessity involve an assumption of the smallest weapon likely to be used in an attack. While this assumption is important, however, it should be recognized that the expected number of stations shown above is based upon single-weapon patterns which would probably not be the case in an actual attack. Pattern overlap due to winds or multiple bursts at the same ground zero can be expected and will tend to enlarge the areas especially of the higher hazards.

Generally accepted planning factors include the assumption that the minimum weapon size expected to be used in an attack is in the order of 1 MT. The fission ratios which these weapons may have, however, are largely a matter of conjecture and often are assumed to be simply 100 percent. To provide an expectation that at least one monitoring point will detect at least the critical hazard state, the spacing of the fixed monitoring points should be in the order of 50 miles. For spacings of 30 miles the expected number of stations in the critical hazard state increases to two stations for a 1-MT weapon. In the nation as a whole, almost three times as many stations would be required for a 30-mile spacing as for the 50-mile grid. Obviously, this is not an insignificant increase in system cost and complexity to gain one more station. On the other hand, the expectation of detecting at least the critical hazard state with stations at 70-mile intervals is not satisfactory.

The constraints on spacing of a fixed monitoring system to detect and define a fallout pattern on a hazard-state area basis alone are readily apparent. However, the accuracy also depends on the degree to which the pattern can be described by contiguous squares. That is, the position of the pattern with respect to the grid is significant. In an extremely irregular and highly convoluted

pattern or one in which the intensity gradients are high, the approximation of the pattern by a square regularly spaced grid will be less accurate than those parts of the pattern where the spatial variations are more gradual and uniform. Of course, depiction of the field by any other technique, such as intensity contours, involves the same difficulties in the highly perturbed and high-gradient portions of the pattern.

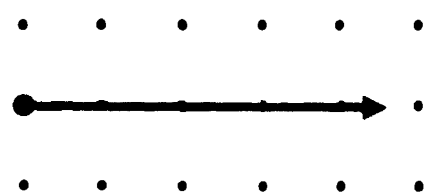
To examine the variations in pattern measurement which occur because of these factors, five individual fallout conditions were examined for grid patterns with stations spaced at intervals of 25 and 50 miles. In all cases, a 10-MT weapon, a mean wind of 15 miles per hour, and a stay time of one week were used. The five situations are shown in Figure 14.

Cases I, II, and III apply to the condition where the weapon ground zero is at a monitoring point and the mean wind forms angles of 0, 45, and 30 degrees, respectively, with the horizontal axis of the station grid. Cases IV and V illustrate the situation where the ground zero is in the center of one monitoring square with the wind blowing at angles of 0 and 45 degrees, respectively, with the horizontal axis of the pattern. The wind arrow illustrates the theoretical position of the pattern hot line. The procedure followed was to superimpose the theoretical fallout pattern on the monitoring station grid and then note the number of monitoring stations within each hazard state. A detail of this process is shown in Figure 15 for Case III.

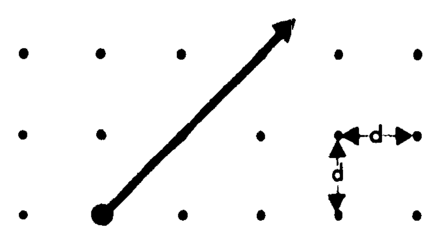
The results of this analysis are illustrated in Table XIX for both grid spacings. For purposes of comparison, the number of stations expected on an area basis are also shown. The quantity of stations in each hazard state generally varies in the range of 25 to 40 percent above and below the value of the expected number of stations based on an area relationship. The total number of stations within the entire pattern, however, has considerably smaller limits. The greatest variation tends to occur in the noncritical and critical hazard states. In the ideal pattern, many of these areas have a tendency to be long narrow strips and therefore are more difficult to characterize by contiguous squares than the extreme and nominal hazard states which tend to include areas that are more consolidated.

Comparing Cases I and IV with the expected number of stations on an area basis for 25-mile spacing clearly illustrates the essential sensitivity of the geometrical relationship between the grid pattern and the fallout pattern with respect to the number of stations detecting the higher hazard states. In Case I the ground zero was located on the station grid, and the wind was assumed to carry the pattern directly down the line of stations; that is, the pattern hot line was coincident with a row of stations. In Case IV the ground zero was translated in both the east-west and north-south directions to the center of a monitoring-station square and the hot line bisected the area between two

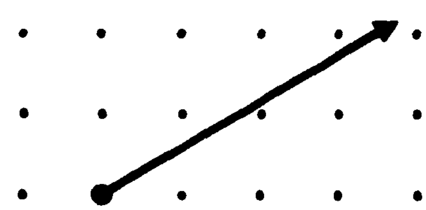
Figure 14
TYPICAL EXPECTED RELATIONSHIPS BETWEEN MONITORING-STATION GRID AND FALLOUT PATTERN HOT LINES



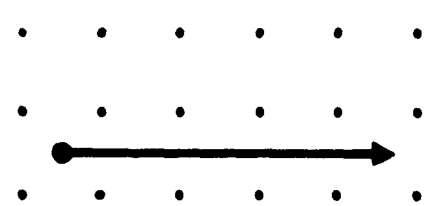
CASE I — Ground-zero located on a monitoring point with wind direction parallel to grid axis



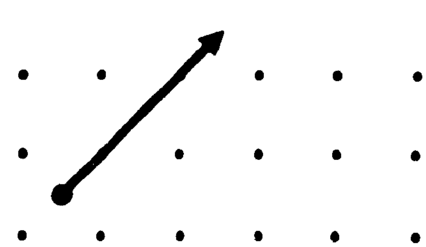
CASE II — Ground-zero located on a monitoring point with wind direction 45° with respect to grid axis



CASE III — Ground-zero located on a monitoring point with wind direction 30° with respect to grid axis



CASE IV — Ground-zero located in center of one monitoring point square with wind direction parallel to grid axis



CASE V — Ground-zero located in center of one monitoring-point square with wind direction 45° with respect to grid axis

Figure 15
TYPICAL HAZARD-STATE IDENTIFICATION PATTERN OF A FIXED MONITORING SYSTEM FOR AN IDEALIZED FALLOUT PATTERN

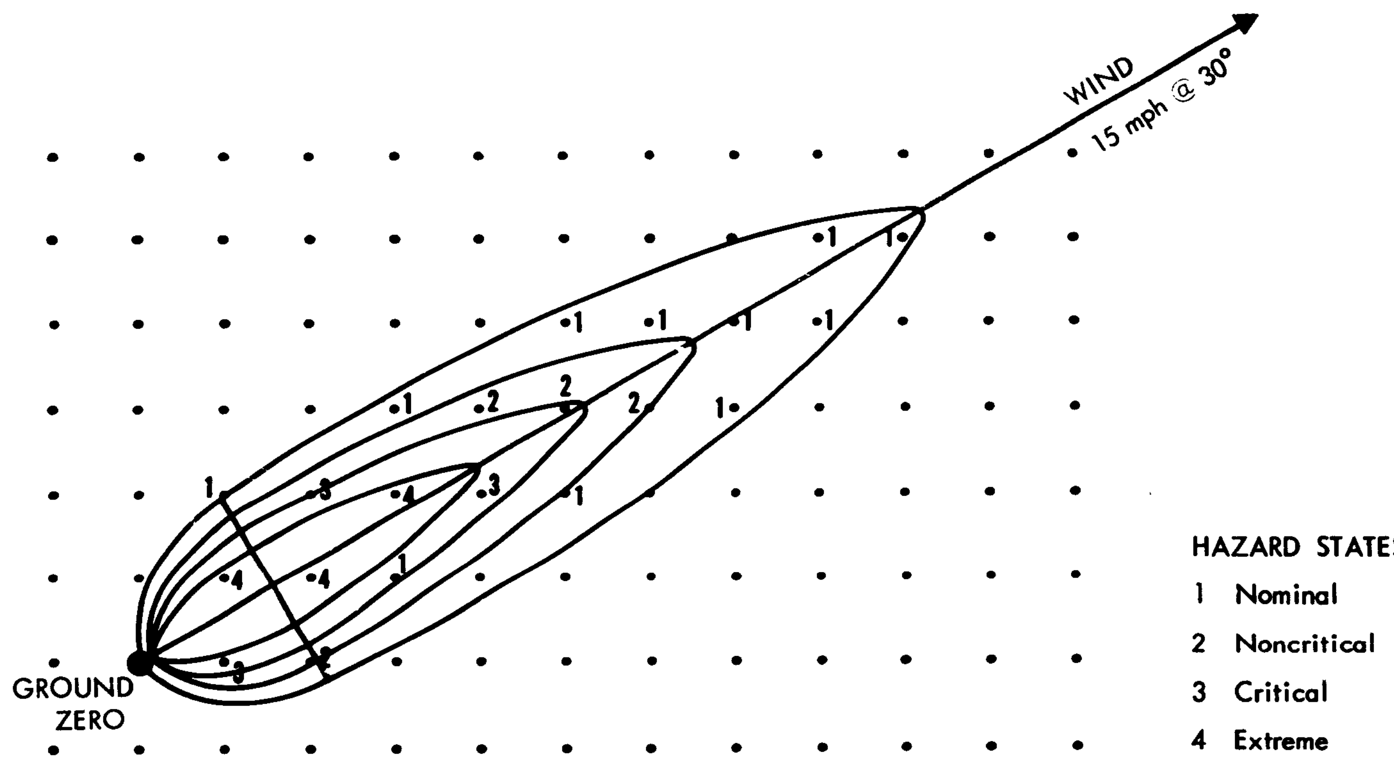


Table XIX

NUMBER OF STATIONS DETECTING EACH HAZARD STATE FOR SELECTED GROUND ZEROS AND WIND DIRECTIONS FOR STATION GRIDS OF 25 AND 50 MILES

	Stations Detecting Hazard State of:								Total Number of Stations	
	Extreme		Critical		Non-critical		Nominal			
	25	50	25	50	25	50	25	50	25	50
Case I	17	4	13	2	11	2	48	14	80	22
Case II	17	3	15	5	10	5	44	9	87	22
Case III	13	3	18	4	13	4	42	11	86	22
Case IV	16	4	20	6	10	4	48	8	94	22
Case V	14	4	16	2	16	2	47	17	93	25
Area basis	12	3	16	4	16	4	48	12	92	23

horizontal rows of stations. Otherwise, the conditions of the two cases were identical. Because in Case IV the cross-wind distance of the extreme hazard state over most of its length was greater than the spacing between stations, nearly twice as many stations detected the area for Case IV than for Case I. Of course, had the cross-wind distance been less than the grid spacing, no stations would have detected the extreme hazard state in Case IV.

It is clear, therefore, that while the expected number of stations to detect hazard states can be developed on an area basis, the actual number to detect these states also depends upon the ultimate shape and orientation of the fallout pattern in relation to the station grid, regardless of the station spacing and grid pattern. Under actual conditions the pattern hot line can be expected to be anything but a straight line; the possibility always exists of the hot line threading a path through the entire monitoring-station grid without ever coinciding with a station.

The use of the results shown in Table XIX to establish station pattern and spacing criteria has limitations because the fallout patterns which must be used in such an analysis are idealized assumptions which may or may not approximate actual conditions. It might be observed, nevertheless, that in general

a slightly better definition of the pattern is obtained when the mean wind is blowing in a direction parallel to the station grid rather than at an angle to it. Although a monitoring system must be designed to detect and measure the fallout situation at the time of war when the fallout winds will have their own unique daily and hourly variations, some guidance for station location may well be derived by considering the mean winds in the areas of probable targets. That is, with the known characteristics of the mean winds, the grid pattern perhaps could be oriented in the most favorable manner with respect to the wind.

Station Spacing for Resource Monitoring

Although the relationships developed above provide valuable guide lines to the location and general pattern of stations in a fixed monitoring system with respect to the phenomenon they are measuring, they do not in themselves provide a conclusive answer as to precisely which pattern and spacing is better than the others. The solution to this problem lies in the broader considerations of the total monitoring system and the requirements of command for radiological information. Radiological information in itself is of limited value and use. Hazard states, doses, and other measures of radiation dangers in an area or at points of interest can be determined, but to have meaning they must be related to the population, industry, and other significant factors in the area that would be affected by the presence of fallout. The accuracy and detail to which these statistical data are known to Administrative Command or any other organizational unit will determine the accuracy and detail which radiological information should possess. Moreover, processing times, display limitations, and related engineering problems must be taken into consideration.

The statistical information required by command is typically aggregated on an area basis and is combined with radiological data to develop damage assessment estimates, initiate planning for the survival and recovery of the nation, and otherwise discharge the command functions. Population, for example, is aggregated on the basis of urban areas, townships, census tracts, or similarly defined regions. Railroad equipment may be described in terms of cars per switching yard or expected number per 100 miles of mainline track. The basis and units of aggregation stem from the level of detail which is required by command, so that the information can be used. Information over and above a certain point of detail often beclouds the picture and creates more confusion and chaos than does gross summary information which is limited in content. Moreover, the greater the detail used in defining a situation, the greater will be the time required for command to gain an understanding of that situation and proceed to act.

Identification and aggregation of the critical national resources involves review of the structure of the national economy and measurement of the contribution which each segment makes to the totality. The probable sequence of

reconstitution of the nation must be established, so that the time phasing and criticality of the myriad required goods and services can be properly ranked. The extent of the interdependence of the basic industries must be known to evaluate those facilities and resources which will most critically affect the reconstruction process and survival itself. In addition, special consideration must be given to those resources which are critically important to the military effort and affect the formulation of military decisions concerning the course of the war as well as perhaps occupation of enemy territory and other postwar military operations.

An immense and continuing effort has been expended during the past decade to analyze these factors. Much of the work has been carried out by the Office of Civil Defense (and its predecessors) and the Defense Atomic Support Agency of the Department of Defense. Similar analyses, somewhat smaller in scope, have been made by universities, private industry, and many other interested organizations. Because of the inherent nature of the nation's economy, especially with respect to the military, the prime resources are subject to constant change. Technological change and advancement, shifting patterns of population and industry, and new modes of transportation, for example, cause the criticality of many areas and resources to undergo frequent transformations. Consequently, identification and aggregation of these resources must be a continuing effort.

From past analyses, however, a number of the basic resources on which the national recovery and war effort are significantly dependent have been identified. These include the following:

1. Population
2. Industrial plant
3. Petroleum refineries
4. Railroad centers
5. Diesel fuel storage
6. Government centers

Other classes of resources, such as major communication terminals, energy sources, water pumping and storage facilities, airfields, and ocean and inland port and docking facilities, are also of extreme importance in many of the early decisions of both civil and military commands. An all-inclusive and final determination of these critical resources, however, is beyond the scope of this analysis. Thus, for illustrative purposes here, the procedure for aggregation of resources will be restricted to the six classes shown above.

Aggregation of the critical resources on a common basis will require detailed analysis of each class. First, the best unit to use for each class must be identified; and from these individual bases the most acceptable common basis

for all classes can be determined. For this analysis, a common base for aggregation has been chosen on an area basis of one degree latitude and one degree longitude of Mercator's projection. These squares are nominally 50-60 miles on a side. Aggregation on this basis is not necessarily the most suitable for developing the pattern and spacing of a fixed monitoring system, but it does provide a demonstration of the technique which can be utilized in developing a uniform aggregation of these critical resources. Figure 16 illustrates the basic grid superimposed on an outline map of the nation. The ordinates and abscissas are scaled in degrees of longitude and latitude. Within each unit area--which in this case can be considered to be the unit area of a monitoring station as well--the critical resources of the nation can be located.

The criticality of the population and general state of industry to the survival and recovery of the nation and the military decisions concerning the course and strategy of the war is self evident. Although the population of the nation today is in excess of 180 million and the area of the nation is approximately 3 million square miles, about two-thirds of the total population resides in about 10 percent of the total area--the 212 standard metropolitan areas as defined by the Bureau of the Census. These metropolitan areas range in size from about 160 square miles for Bridgeport, Connecticut, to approximately 8,000 square miles for the Duluth-Superior area. The geographical limits of these areas are, of course, defined for enumeration and other purposes of the Bureau of the Census. As is well known, the population pattern in these areas tends to have a high density within the central city and a decreasing density as the distance from the city increases. Each area, of course, has its own unique variations to this general trend. Consequently, to highlight the basic pattern of population distribution as it affects the design of a monitoring system, only those central cities of the metropolitan areas with populations in excess of 100,000 will be considered.

In 1960,129 cities in the continental United States* had populations in excess of 100,000. These are listed in Table XX, and their locations are shown in Figure 17, in terms of the one-degree grid. Most of these cities are, of course, located in the northeastern section of the nation with as many as five situated within the same grid-square. This density gradually decreases in a westerly direction with a cluster on the Pacific Coast. These 129 central cities account for about 30 percent of the total population, and within their total urban areas they include approximately 60 percent of the population. Clearly, these areas should receive high priority especially in early damage assessment and casualty estimation operations.

---

* In this report, exclusive of Alaska.

Figure 16
SAMPLE BASE FOR AGGREGATION OF CRITICAL RESOURCES: UNIT AREAS OF ONE-DEGREE OF MERCATOR'S PROJECTION

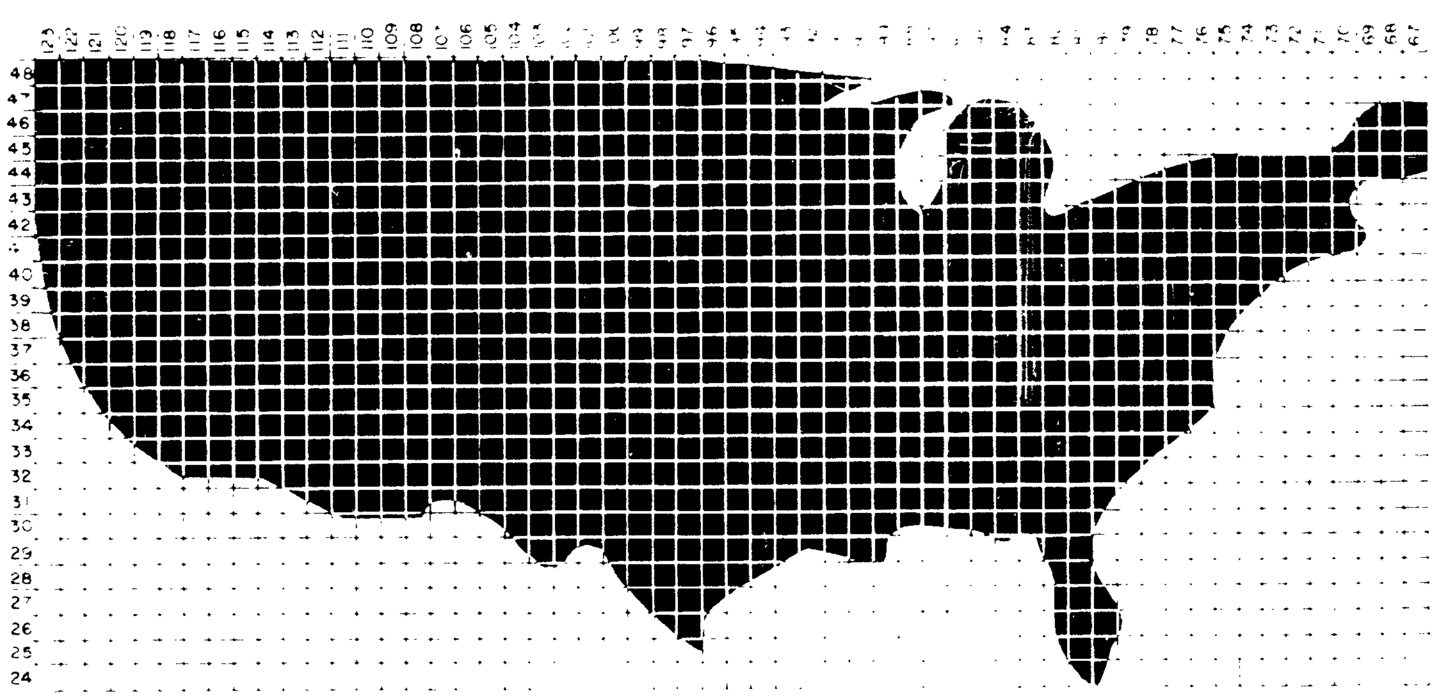


Table XX

CENTRAL CITIES IN THE CONTINENTAL UNITED STATES
WITH POPULATIONS IN EXCESS OF 100,000 IN 1960

Region 1

Connecticut
- Bridgeport
- Hartford
- New Haven
- Waterbury

Massachusetts
- Boston
- Cambridge
- New Bedford
- Springfield
- Worcester

New York
- Albany
- Buffalo
- New York
- Niagara Falls
- Rochester
- Syracuse
- Utica
- Yonkers

New Jersey
- Camden
- Elizabeth
- Jersey City
- Newark
- Paterson
- Trenton

Rhode Island
- Providence

Region 2

Kentucky
- Louisville

Maryland
- Baltimore

Ohio
- Akron
- Canton
- Cincinnati
- Cleveland
- Columbus
- Dayton
- Toledo
- Youngstown

Pennsylvania
- Allentown
- Erie
- Philadelphia
- Pittsburgh
- Scranton

Virginia
- Newport News
- Norfolk
- Portsmouth
- Richmond

District of Columbia
- Washington

Region 3

Alabama
- Birmingham
- Mobile
- Montgomery

Florida
- Jacksonville
- Miami
- St. Petersburg
- Tampa

Georgia
- Atlanta
- Columbus
- Savannah

Mississippi
- Jackson

North Carolina
- Charlotte
- Greensboro
- Winston-Salem

Tennessee
- Chattanooga
- Knoxville
- Memphis
- Nashville

Table XX (continued)

Region 4

Illinois

Chicago
Peoria
Rockford

Indiana

Evansville
Fort Wayne
Gary
Hammond
Indianapolis
South Bend

Michigan

Dearborn
Detroit
Flint
Grand Rapids
Lansing

Missouri

Kansas City
St. Louis

Wisconsin

Madison
Milwaukee

Region 5

Arkansas

Little Rock

Louisiana

Baton Rouge
New Orleans
Shreveport

New Mexico

Albuquerque

Oklahoma

Oklahoma City
Tulsa

Texas

Amarillo
Austin
Beaumont
Corpus Christi
Dallas
El Paso
Fort Worth
Houston
Lubbock
San Antonio
Wichita Falls

Region 6

Colorado

Denver

Iowa

Des Moines

Kansas

Kansas City
Topeka
Wichita

Minnesota

Duluth
Minneapolis
St. Paul

Nebraska

Lincoln
Omaha

Region 7

Arizona

Phoenix
Tucson

California

Anaheim
Berkeley
Fresno
Glendale
Long Beach
Los Angeles
Oakland
Pasadena
Sacramento
San Diego
San Francisco
San Jose
Santa Ana
Torrance

Utah

Salt Lake City

Table XX (concluded)

Region 8

Oregon

Portland

Washington

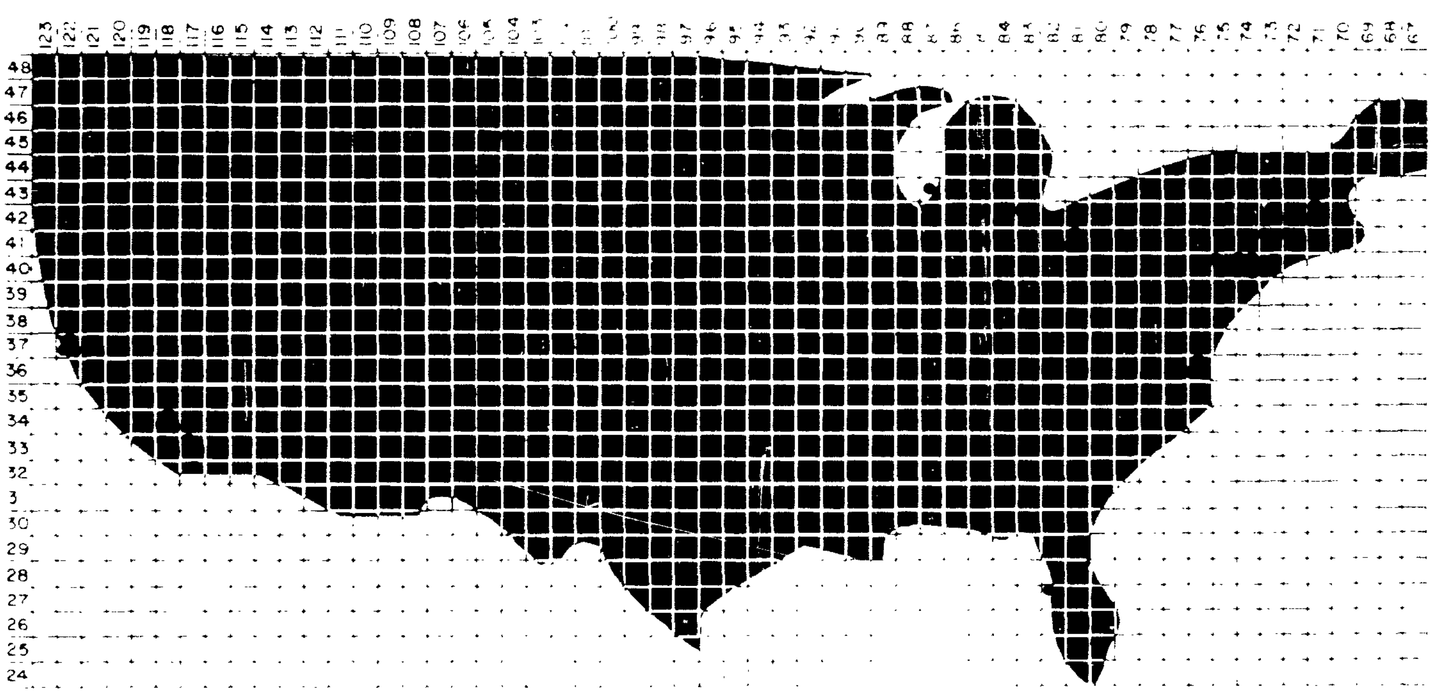
Seattle
Spokane
Tacoma

Source: Statistical Abstract of the United States, 1962, U. S. Department of Commerce, Bureau of the Census

In addition to population, the capability and state of the nation will depend upon the status of its industrial plant. Radiation information will be useful in assessing casualties among the population which operates the plant and also may permit gross estimation of the time at which areas can be re-entered, reclamation initiated, and production resumed. On a broad area basis the over-all damage to the nation's industrial plant and the significance of the facilities in the area with respect to their being monitored can be identified in terms of the manufactured value added to the nation's economy by the production facilities within a unit area. Manufacturing centers in 124 cities annually contribute substantially more than 50 percent of the value added by manufacturing to the national economy. These cities are identified in Table XXI and shown on an area basis in Figure 18. As expected, many of these cities appear on the list of cities of more than 100,000 population. Only 25 of the populous cities are not included in this class of resources. However, it might be noted that on a larger metropolitan area criterion under which the population distribution could also be treated, the relationship of population indicators to value added indicators would be virtually one-for-one.

Monitoring information from population centers and manufacturing areas provides a broad characterization of the state of the nation following the attack. It is difficult to visualize any meaningful command decisions being made without these data. In addition to these somewhat generalized classes of information, planning for recovery and support of the military also may require data on specific installations and facilities. These, typically, are facilities that serve a basic function in war and recovery which, if lost or rendered inoperable, affect fundamental planning and operational decisions.

Figure 17
LOCATION OF CENTRAL CITIES IN THE CONTINENTAL UNITED STATES WITH POPULATIONS IN EXCESS OF 100,000



Source: Statistical Abstract of the United States, 1962, U. S. Department of Commerce, Bureau of the Census

Table XXI

124 LEADING MANUFACTURING CENTERS IN THE CONTINENTAL UNITED STATES

Region 1

Connecticut

Bridgeport
Hartford
New Britain-Bristol
New Haven
Stanford-Norwalk
Waterbury

Massachusetts

Boston
Lowell-Lawrence
New Bedford-Fall River
Pittsfield
Springfield-Holyoke
Worcester

New Jersey

Trenton

New York

Binghampton
Buffalo
New York-Northeast New Jersey
Rochester
Schenectady-Albany-Troy
Syracuse

Rhode Island

Utica-Rome
Providence

Region 2

Delaware

Dover
Wilmington

District of Columbia

Washington

Kentucky

Louisville

Maryland

Baltimore

Ohio

Akron
Canton
Cleveland
Cincinnati
Columbus
Dayton
Hamilton-Middleton
Lorain-Elyria
Toledo
Youngstown

Pennsylvania

Allentown-Bethlehem-Easton
Erie
Harrisburg
Lancaster
Philadelphia-Camden, N.J.
Pittsburgh
Reading
Scranton
Wilkes Barre-Hazelton
York

Virginia

Norfolk-Portsmouth
Richmond

West Virginia

Charleston
Huntington-Ashland
Wheeling-Steubenville

Region 3

Alabama

Birmingham
Mobile
Montgomery

Florida

Jacksonville
Miami
Tampa-St. Petersburg

Georgia

Atlanta
Savannah

Table XXI (continued)

North Carolina

- Winston-Salem

South Carolina

- Charleston
- Greenville

Tennessee

- Chattanooga
- Knoxville
- Memphis
- Nashville
- Oak Ridge

Region 4

Illinois

- Chicago
- Peoria
- Rockford
- Springfield

Indiana

- Evansville
- Fort Wayne
- Indianapolis
- South Bend

Michigan

- Detroit
- Flint
- Grand Rapids
- Kalamazoo
- Lansing
- Saginaw

Missouri

- Kansas City
- St. Louis

Wisconsin

- Madison
- Milwaukee
- Racine-Kenosha

Region 5

Arkansas

- Little Rock-North Little Rock

Louisiana

- Baton Rouge
- New Orleans
- Shreveport

New Mexico

- Albuquerque
- Los Alamos

Oklahoma

- Oklahoma City
- Tulsa

Texas

- Austin
- Beaumont-Port Arthur
- Corpus Christi
- Dallas
- El Paso
- Fort Worth
- Houston
- San Antonio

Region 6

Colorado

- Denver

Iowa

- Davenport-Rock Island-Moline
- Des Moines

Kansas

- Topeka
- Wichita

Minnesota

- Duluth-Superior
- Minneapolis

Nebraska

- Lincoln
- Omaha

Wyoming

- Cheyenne

Region 7

Arizona

- Phoenix

California

- Los Angeles-Long Beach
- Sacramento
- San Bernardino-Riverside-Ontario

Table XXI (concluded)

Region 7 (cont.)

California (cont.)

San Diego
San Jose
San Francisco-Oakland

Utah

Salt Lake City

Region 8

Oregon

Portland

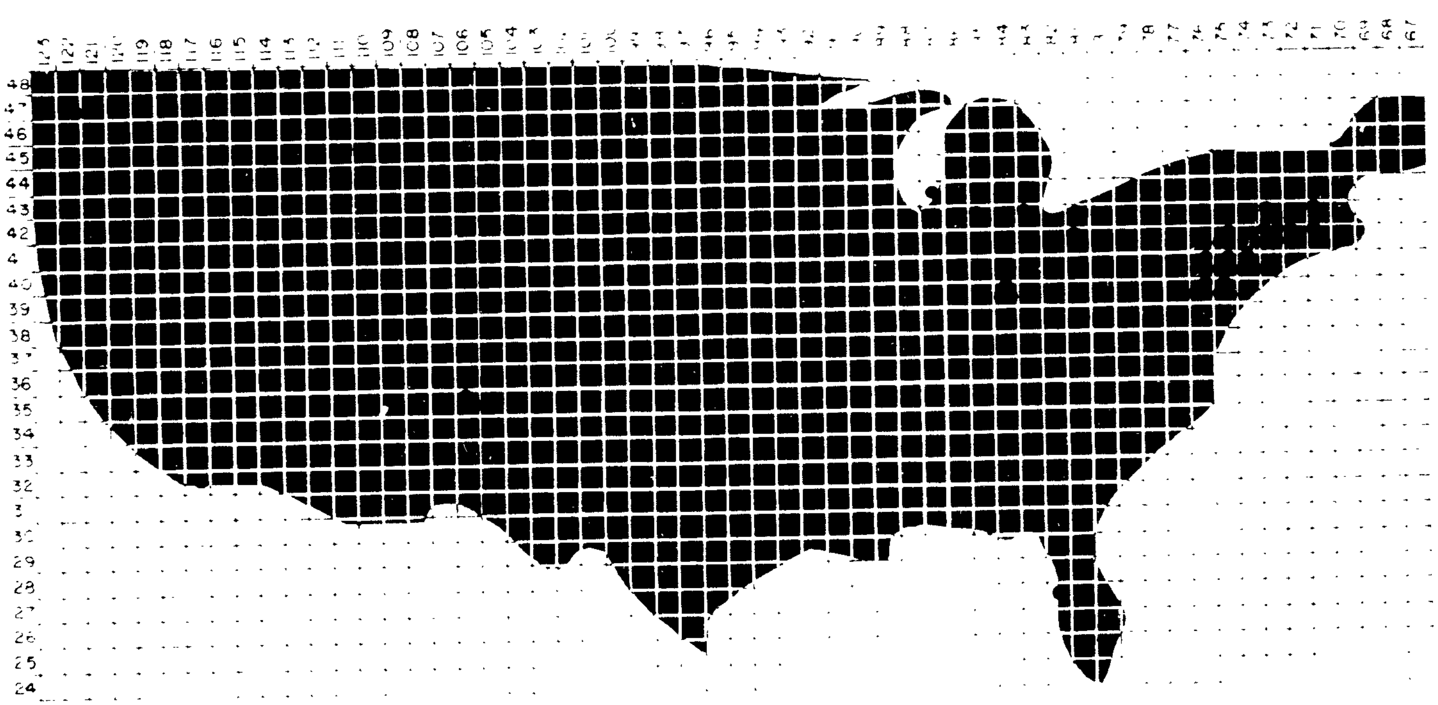
Washington

Seattle
Spokane
Tacoma

Source: E. D. Callahan, et. al., The Probable Fallout Threat over the Continental United States, Report No. TO-B 60-13, Prepared for Office of Civil and Defense Mobilization, Under Contract No. CDM-SR-59-33, Technical Operations Incorporated, Burlington, Mass., December 1960

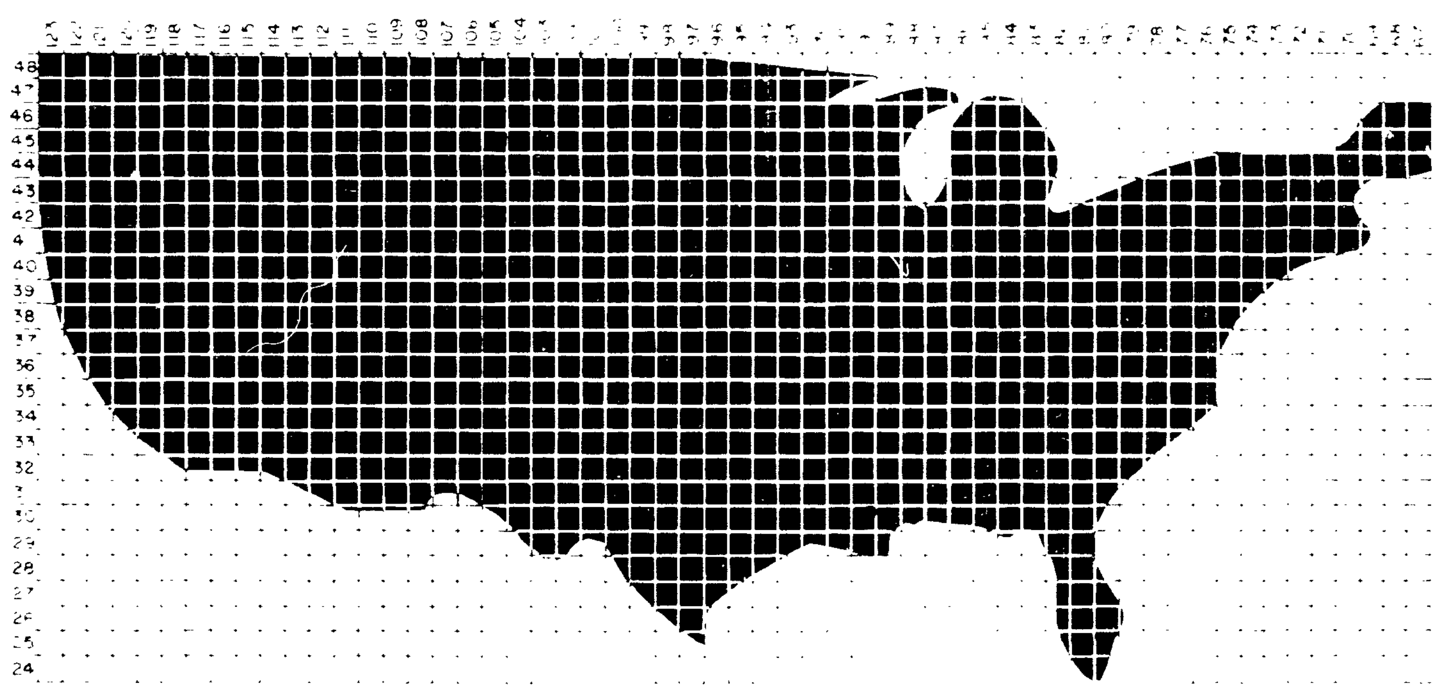
Petroleum refineries are one of the most significant resources in this class. The dependence of the nation on these facilities is basic. Oil, gasoline, and most other petroleum products are required during almost every segment of recovery to drive farm machinery, to power transportation, to create electric energy (along with coal), and to support the movement and deployment of military forces in this nation and throughout the world. The location pattern and capacity of the petroleum industry are in a state of constant change, with new facilities being built and old units being modified or retired as the demand for petroleum products grows and changes. The geographic location pattern of the refineries is shown in Figure 19, where the major facilities are aggregated on the standard one-degree squares. A total of 51 areas account for virtually the entire refining capability of the nation. Their pattern in contrast to population and industry is more uniform across the nation but with some slight

Figure 18
LOCATION OF 124 LEADING MANUFACTURING CENTERS



Source: E. D. Callahan, et. al., The Probable Fallout Threat over the Continental United States, Report No. TO-B 60-13, Prepared for Office of Civil and Defense Mobilization, Under Contract No. CDM-SR-59-33, Technical Operations Incorporated, Burlington, Mass., December 1960

Figure 19
LOCATION OF MAJOR PETROLEUM REFINING AREAS



Source: Resource Compendium for Civil Defense Damage Assessment Program, Prepared for Federal Civil Defense Administration, Stanford Research Institute, 1956

concentration along the sea coasts and the Middle West around the Great Lakes. These points are specifically identified in Table XXII.

Table XXII

MAJOR PETROLEUM REFINING AREAS

Region 1

- New York-Northeast New Jersey
- Providence

Region 2

- Baltimore
- Boston-Lowell-Lawrence
- Canton
- Charleston, W. Va.
- Cincinnati
- Cleveland
- Huntington-Ashland
- Lima
- Louisville
- Philadelphia
- Pittsburgh
- Toledo
- Wilmington
- Youngstown

Region 3

- Charleston, S.C.
- Memphis
- Mobile
- Nashville
- Savannah

Region 4

- Bay City, Mich.
- Chicago
- Detroit
- Duluth-Superior
- Grand Rapids
- Indianapolis
- Kalamazoo
- St. Louis

Region 5

- Amarillo
- Baton Rouge
- Beaumont-Port Arthur
- Corpus Christi
- El Paso
- Fort Worth
- Galveston
- Houston
- New Orleans
- Oklahoma City
- San Antonio
- Shreveport
- Tulsa
- Wichita Falls

Region 6

- Denver
- Kansas City, Mo.
- Minneapolis-St. Paul
- Wichita

Region 7

- Los Angeles
- Salt Lake City
- San Francisco-Oakland

Region 8

- Portland, Ore.

Source: Resource Compendium for Civil Defense Damage Assessment Program, Prepared for Federal Civil Defense Administration, Stanford Research Institute, 1956

A second highly critical class of national resources is the major rail centers. Railroads carry in excess of 50 percent of the intercity freight traffic during peacetime. The demand on rail facilities during war and the recovery period likely would not decrease below this demand and could increase significantly. In contrast to petroleum refining facilities, the railroad plant is a network covering large areas rather than a number of units located at discrete points. However, as in the case of most well-developed networks, the railroad plant consists of a relatively small number of nodes and a large number of links between the nodes. The nodes somewhat automatically emerge as the most critical part of the network, and the condition of the total plant can be more easily summarized in terms of the few nodes rather than the numerous links. Moreover, in a fallout environment the dose received by railroad personnel could be expected to be much greater in the rail centers, where car loading, switching, and other work must be carried out under unshielded conditions, than the dose received during actual operation of trains along the network links. Locomotives and cars often provide appreciable radiation protection.

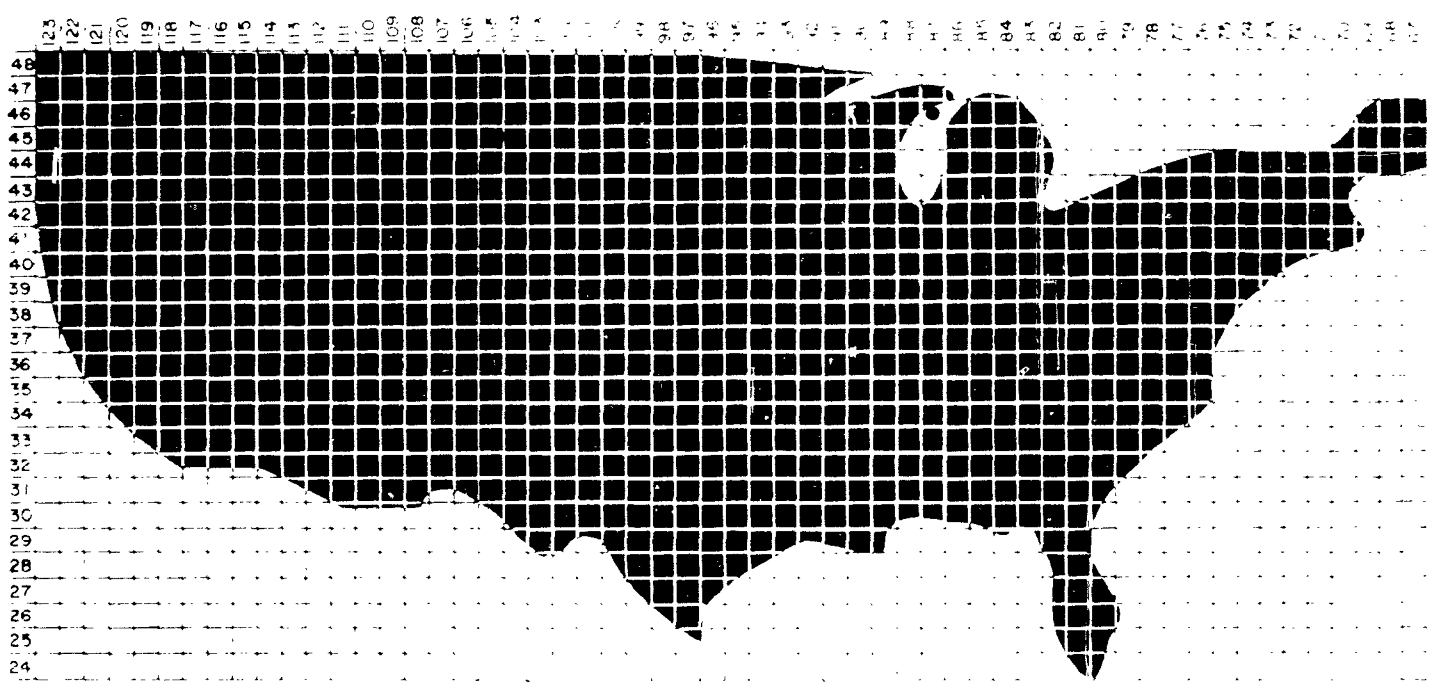
A total of 37 centers have been identified as major nodes in the railroad system of the nation. On an area basis of one-degree squares their location pattern is illustrated in Figure 20 and identified specifically in Table XXIII. Their general pattern is similar to that of industrial activity, as would be expected, but the locations are more widely dispersed across the nation.

As an adjunct to information concerning both petroleum refineries and rail centers, the status of diesel fuel storage throughout the nation should be of great significance in the early phases of the war and recovery. Decisions regarding decontamination and start-up of refineries, rail movements, and many other matters may in large part depend upon the ability to utilize existing stocks of diesel oil.

The location pattern of diesel fuel storage facilities in excess of 100,000 gallons is shown in Figure 21 and listed in Table XXIV. The pattern roughly approximates that of the major rail centers and the mainline rail links of the nation. The greatest concentration of diesel fuel storage facilities is in the eastern section of the nation. Comparison of this pattern with the refinery locations in Figure 19 also shows a general similarity. As can be noted in Table XXIV, an extremely wide variation occurs in the actual capacity of these storage facilities, so that some installations are of far greater significance than others.

A final typical class of installations about which early radiological information is required is the government centers of the nation. Survival and recovery obviously depend heavily upon proper command. As early as possible, Administrative Command must know the status of those subordinate installations which will implement in detail the general policy and operational decisions.

Figure 20
LOCATION OF MAJOR RAILROAD CENTERS



Source: Jones, Paul S., The Effects of a Nuclear Attack on Rail Activity Centers, prepared for Office of Civil and Defense Mobilization, Under Contract No. CDM-SR-CO-37, Stanford Research Institute

Many of these government centers will be in communication with Administrative Command and will therefore be able to report their radiological status directly. Nevertheless, because of organizational and systems breakdowns or possible delays in reporting, Administrative Command may desire an independent method by which it can assess the radiological situation at government centers.

Table XXIII

MAJOR RAILROAD CENTERS

Region 1

- Boston, Mass.
- Buffalo, N.Y.
- New York, N.Y.

Region 2

- Baltimore, Md.
- Charleston, W. Va.
- Cincinnati, Ohio
- Cleveland, Ohio
- Louisville, Ky.
- Norfolk, Va.
- Philadelphia, Pa.
- Pittsburgh, Pa.
- Scranton, Pa.
- Toledo, Ohio
- Youngstown, Ohio

Region 3

- Atlanta, Ga.
- Birmingham, Ala.
- Memphis, Tenn.
- Tampa, Fla.

Region 4

- Chicago, Ill.
- Detroit, Mich.
- Duluth, Minn.
- Indianapolis, Ind.
- Marquette, Mich.
- Minneapolis, Minn.
- Peoria, Ill.

Region 5

- Dallas, Tex.
- Houston, Tex.
- New Orleans, La.

Region 6

- Denver, Colo.
- Kansas City, Mo.
- Omaha, Nebr.
- St. Louis, Mo.

Region 7

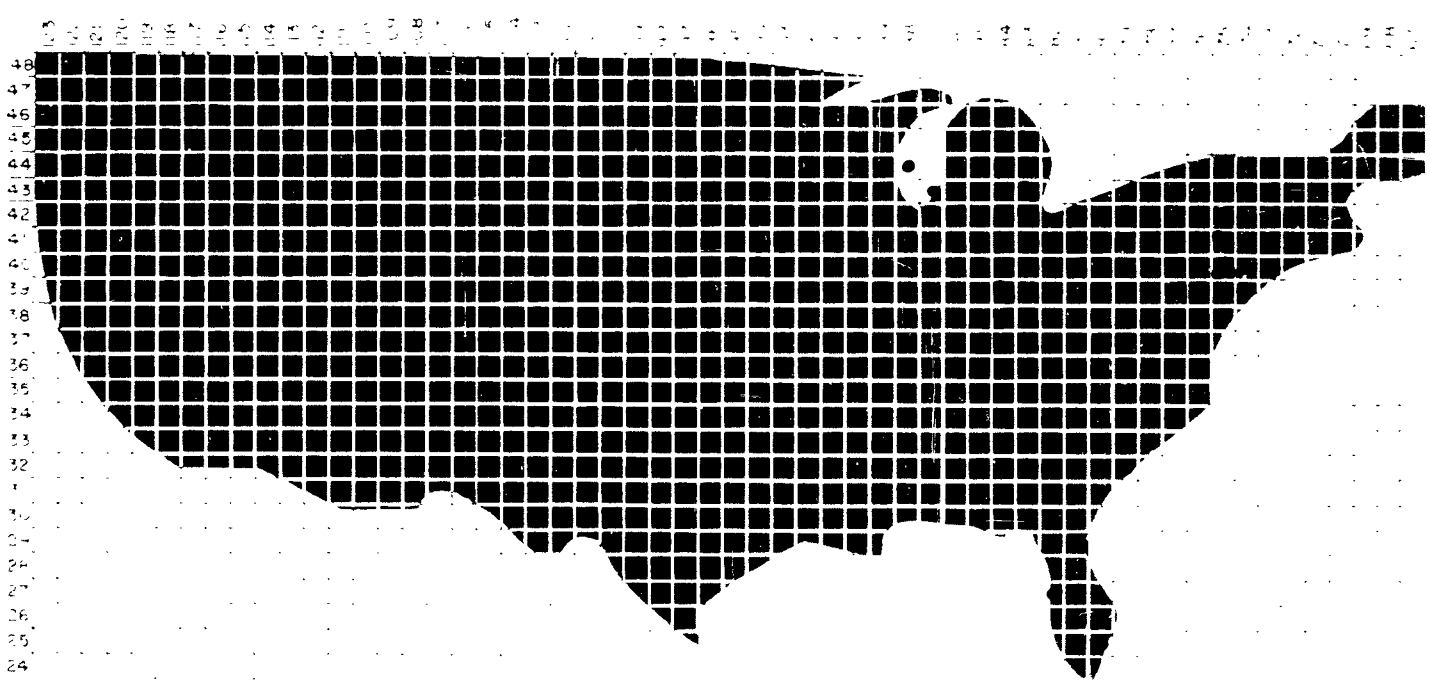
- Los Angeles, Calif.
- Salt Lake City, Utah
- San Francisco, Calif.

Region 8

- Portland, Ore.
- Seattle, Wash.

Source: Jones, Paul S., The Effects of a Nuclear Attack on Rail Activity Centers, prepared for Office of Civil and Defense Mobilization, Under Contract No. CDM-SR-CO-37, Stanford Research Institute

Figure 21
LOCATION OF DIESEL FUEL STORAGE FACILITIES IN EXCESS OF 100,000 GALLONS



Source: Dixon, Harvey L., Diesel Fuel Storage Facilities and Average Diesel Fuel Stocks for Class I Railroads in the United States, prepared for Office of Civil and Defense Mobilization, under Contract No. CDM-SR-60-19

Table XXIV

DIESEL FUEL STORAGE FACILITIES IN EXCESS OF 100,000 GALLONS

Location	Capacity (thousands of gallons)
Region 1	
Maine	
Portland	451
Massachusetts	
Springfield-Holyoke	412
New Jersey	
New York, Northeast New Jersey	4,419
New York	
Albany-Schenectady-Troy	3,212
Binghampton	469
Buffalo	3,702
Syracuse	6,042
Utica-Rome	228
Region 2	
Delaware	
Wilmington	273
District of Columbia	
Washington	1,481
Kentucky	
Huntington-Ashland	756
Louisville	1,442
Maryland	
Baltimore	260

Table XXIV (continued)

Location	Capacity (thousands of gallons)
Region 2 (cont.)	
Ohio	
Akron	134
Canton	789
Cincinnati	858
Cleveland	1,723
Columbus	2,217
Dayton	100
Lima	271
Toledo	756
Wheeling-Steubenville	842
Youngstown	677
Pennsylvania	
Allentown-Bethlehem-Easton	464
Erie	1,879
Harrisburg	7,106
Philadelphia	866
Pittsburgh	10,817
Reading	534
Scranton	1,437
Wilkes-Barre-Hazleton	1,082
Virginia	
Norfolk-Portsmouth	390
Richmond	669
Roanoke	1,502
Region 3	
Alabama	
Birmingham	3,255
Montgomery	933

Table XXIV (continued)

Location	Capacity (thousands of gallons)
Region 3 (cont.)	
Florida	
Jacksonville	1,824
Miami	350
Tampa-St. Petersburg	1,371
Georgia	
Atlanta	5,439
Augusta	794
Columbus	470
Macon	1,148
Savannah	523
North Carolina	
Asheville	500
South Carolina	
Charleston	140
Columbia	1,017
Tennessee	
Chattanooga	1,915
Knoxville	1,230
Memphis	908
Nashville	546
Region 4	
Illinois	
Chicago	15,673
Davenport-Rock Island-Moline	380
Decatur	726
Peoria	697
St. Louis	7,374
Springfield	129
Evansville	1,196

Table XXIV (continued)

Location	Capacity (thousands of gallons)
Region 4 (cont.)	
Indiana	
Indianapolis	680
Michigan	
Detroit	976
Flint	208
Grand Rapids	1,061
Jackson	550
Saginaw	210
Calhoun	1,244
Springfield	6,600
Wisconsin	
Duluth-Superior	933
Green Bay	537
Milwaukee	1,207
Region 5	
Arkansas	
Little Rock-North Little Rock	4,820
Louisiana	
New Orleans	1,813
Shreveport	2,084
Oklahoma	
Tulsa	210
Texas	
Amarillo	2,563
Dallas	2,591
El Paso	150

Table XXIV (continued)

Location	Capacity (thousands of gallons)
Region 5 (cont.)	
Texas (cont.)	
Fort Worth	124
Houston	2,142
San Antonio	961
Waco	2,816
Region 6	
Colorado	
Denver	1,217
Pueblo	187
Iowa	
Des Moines	1,106
Omaha	2,921
Sioux City	634
Waterloo	514
Wichita	100
Minnesota	
Minneapolis-St. Paul	2,628
Nebraska	
Lincoln	2,349
Region 7	
Arizona	
Phoenix	840
Tucson	440

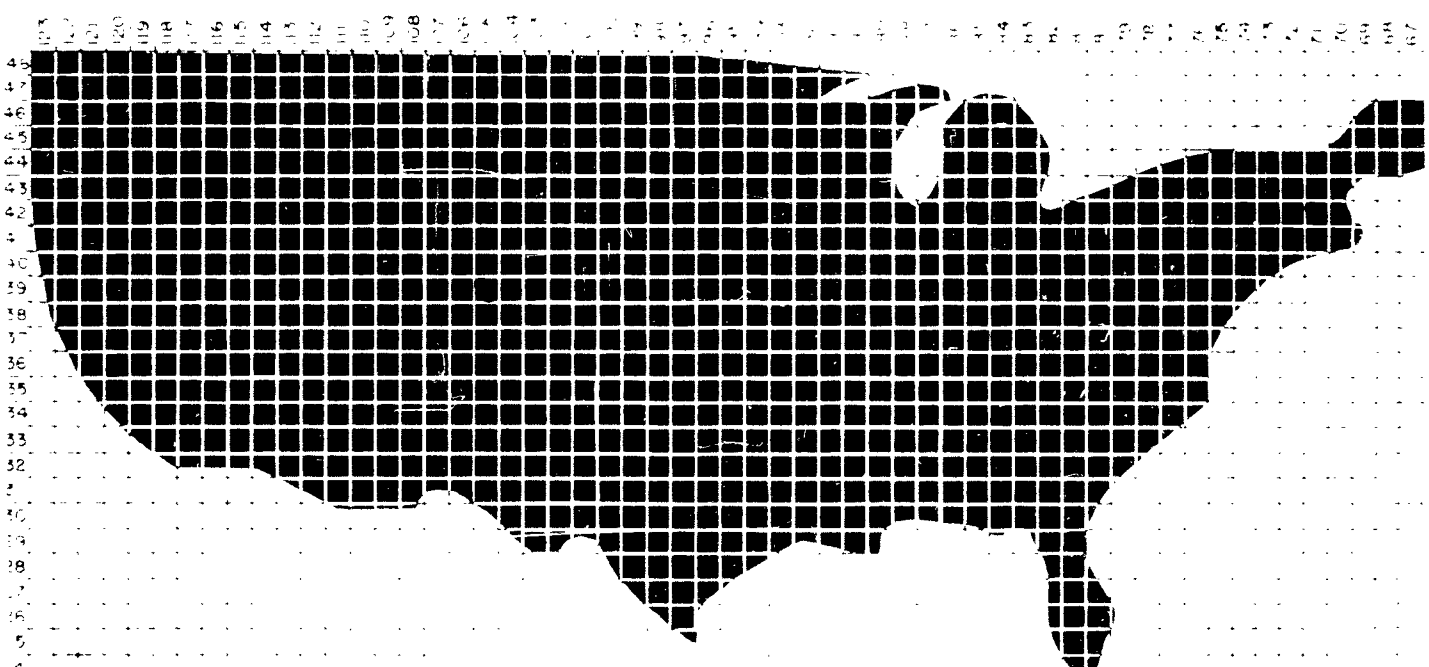
Table XXIV (concluded)

Location	Capacity (thousands of gallons)
Region 7 (cont.)	
California	
Los Angeles-Long Beach	1,177
San Bernardino-Riverside-Ontario	2,356
San Francisco-Oakland	2,421
Utah	
Ogden	1,767
Salt Lake City	2,458
Region 8	
Oregon	
Portland	6,220
Washington	
Seattle	2,564
Spokane	776
Tacoma	1,344

Source: Dixon, Harvey L., Diesel Fuel Storage Facilities and Average Diesel Fuel Stocks for Class I Railroads in the United States, prepared for Office of Civil and Defense Mobilization, under Contract No. CDM-SR-60-19

Figure 22 illustrates the geographic distribution of a representative group of important government centers, including the national capital, the eight civil defense regional headquarters, and the capitals of the 48 continental states. Other government centers,such as any planned relocation points of government centers, should probably be included in any more detailed analyses. Certain military installations undoubtedly should be similarly treated.

Figure 22
LOCATION OF GOVERNMENT CENTERS



Many classes of the critical resources discussed above are essentially geographically coincident because similar economic and natural geographic factors affect their locations. The degree to which they are commonly located depends to some extent upon the common basis on which they are aggregated. Population and industry usually have the same general distribution since one cannot exist without the other in today's economy. Because the railroad network exists to serve these two, its major facilities logically are located near centers of industry. On the basis of the one-degree aggregation, the manner in which these critical resources accumulate is shown on Figure 23.

The relationship of the number of critical resources in the nation is summarized in Table XXV for the eight civil defense regions. A total of 498 resource points have been identified here. As can be noted the tendency is for these resources to pyramid in certain regions. The heavy concentration of these resources is in the east with a gradual decrease toward the west, except on the Pacific Coast where a second concentration occurs. The only appreciable scatter develops from the government centers whose locations normally are based on criteria independent of nearly all other resources. Military installations would show a similar dispersion.

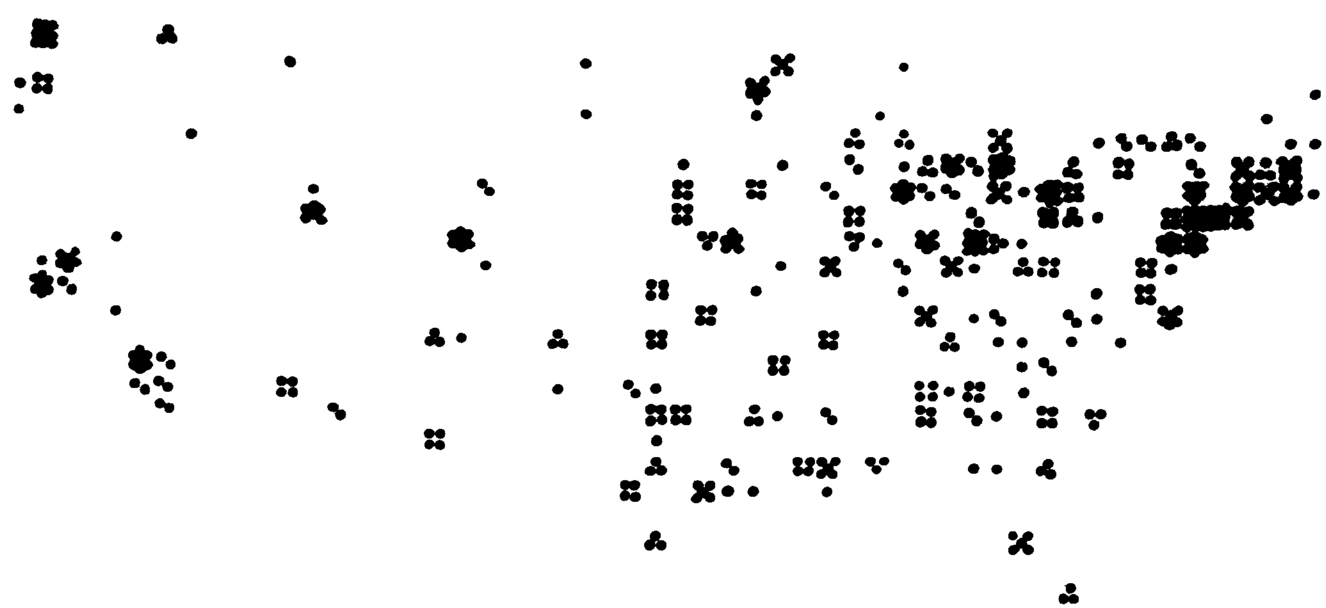
Table XXV

NUMBER OF CRITICAL RESOURCES WITHIN PRESENT CIVIL DEFENSE REGIONS

	Region								
Resource	1	2	3	4	5	6	7	8	Total
Population	24	20	18	18	18	10	17	4	129
Manufacturing	21	30	16	19	16	10	8	4	124
Diesel fuel storage	8	26	17	18	11	9	7	4	100
Refineries	2	14	5	8	14	4	3	1	51
Rail centers	3	11	4	7	3	4	3	2	37
Government centers	9	9	8	6	6	9	5	5	57
Total	67	110	68	76	68	46	43	20	498

The implication of these trends on the design of a fixed monitoring system is readily apparent. Because of the concentration of critical resources at a relatively small number of locations, a system which monitors the radiological situation for one class of resources will at the same time provide coverage

Figure 23
SUMMARY OF LOCATIONS OF CRITICAL RESOURCES



of other classes as well. With information from a relatively small number of monitoring points, an estimate of the radiological hazard situation for a large proportion of the critical resources of the nation can be developed. The broader the base for aggregation of information on these resources the greater will be the extent to which these resources will be commonly located, but of course the more general will be the results of hazard assessment.

Aggregation on a one-degree basis shown here suggests the general approach which should be used to make a final determination of the spacing of fixed monitoring stations. As was shown previously with respect to the geometrical variation of hazard and injury states within a fallout pattern, station spacing in the order of 50 miles should be adequate to detect at least the critical hazard state for the smallest weapons expected, i.e., 1 MT. The test of the acceptability of this or any other spacing, however, must include the specification of the accuracy to which the radiological condition must be known at the critical resources. In general, the greater the significance of the resource to early operations, the smaller should be the acceptable error in monitoring. This consideration, of course, is an integral part of the process of selecting the most suitable basis of resource aggregation. However, there may well be certain very select and extraordinarily critical classes of resources which are not suitable for aggregation on any basis. Certain quasi-military civil resources, such as missile parts depots and weapon assembly plants, may be typical of this class. Such installations should be handled individually. Placement of monitoring equipment at each specific site would be preferable to reducing the scale of the common aggregate base in an attempt to adequately monitor those installations that are unsuitable for aggregation.

Station Reporting Procedures

The procedures by which fixed monitoring stations report their radiation measurements can be divided into two basic parts as a function of the changes in the field--the period of radiation build-up, which generally develops with rapidity in a relatively short time, and the period of decay, which is a long-term gradual process. The time at which build-up begins and the period over which it continues are a function of the distance from ground zero, the winds, and the weapon yield. The decay time of interest is primarily a function of the peak intensity and the decay rate. Because of the vastly different time scales of build-up and decay, the reporting procedures in these two phases should be correspondingly different.

During the build-up period, a station is instructed to report when a predesignated intensity level, such as a change in hazard state, has been reached. At this time the station first transmits a lockout character to suppress other stations until the transmission is completed. The message would

consist of at least the intensity and the station designation. Other information, such as time, appears to be optional. During the decay period each station is interrogated by the command headquarters with the station responding with a report of the radiation it observes at the time of interrogation. This mode of operation appears desirable for purposes of maintenance and calibration during peacetime as well. Command must have control over the information which it receives. To have a system reporting on a fixed-time basis, for example, could easily tend to saturate the command system and require analysis and processing of information not significantly different from earlier reports. Moreover, once the situation begins to stabilize, the attention of command should be focused on those areas of greatest significance to recovery where command assistance is most needed. During the decay period, of course, radiological information should be available from local forces and other monitoring systems; this information generally will be in considerably more detail and accuracy than that derived from the fixed monitoring system.

Reporting during Intensity Build-up

Station reporting procedures during the fallout period depend upon the time of arrival, the build-up characteristics, and the intensities to be reported. The determination of the time of arrival of fallout after detonation should be divided into two parts. The first includes those areas close to ground zero which are blanketed with material falling almost straight down from the initial cloud and stem. The second, and by far the greater area, is that covered by material carried by the winds to great distances.

The area affected by materials falling directly from the initial cloud depends on the dimensions of the cloud which is in turn a function of the weapon yield. Generally, the cloud radius increases as a function of yield although at a rate far less than yield. The height of the cloud increases with yield so that normally the arrival time for fallout from the initial cloud increases with yield because the particles have a greater fall distance. Typical arrival times for material falling directly from the initial cloud have been reported by Shnider and Shapiro.[14] The variation of arrival times for weapons in the range of 1-50 MT is about 0.4 of an hour. For a 1 MT weapon the material in the 30-roentgen contour has an arrival time of 0.18 hours while the time for the 50 MT weapon increases to about 0.6 hours. The arrival time decreases as the distance to ground zero decreases. For operational purposes of radiological instrumentation, however, the relationship soon becomes of academic interest only as the direct effects of the weapon supersede fallout as the prime hazard.

The time of arrival in areas not under the initial cloud depends primarily on the wind speed between the ground zero and the downwind point. Other

parameters, such as initial particle altitude and particle size, contribute to arrival time as well as to the intensity build-up. A gross method of estimating the arrival time of wind borne fallout is

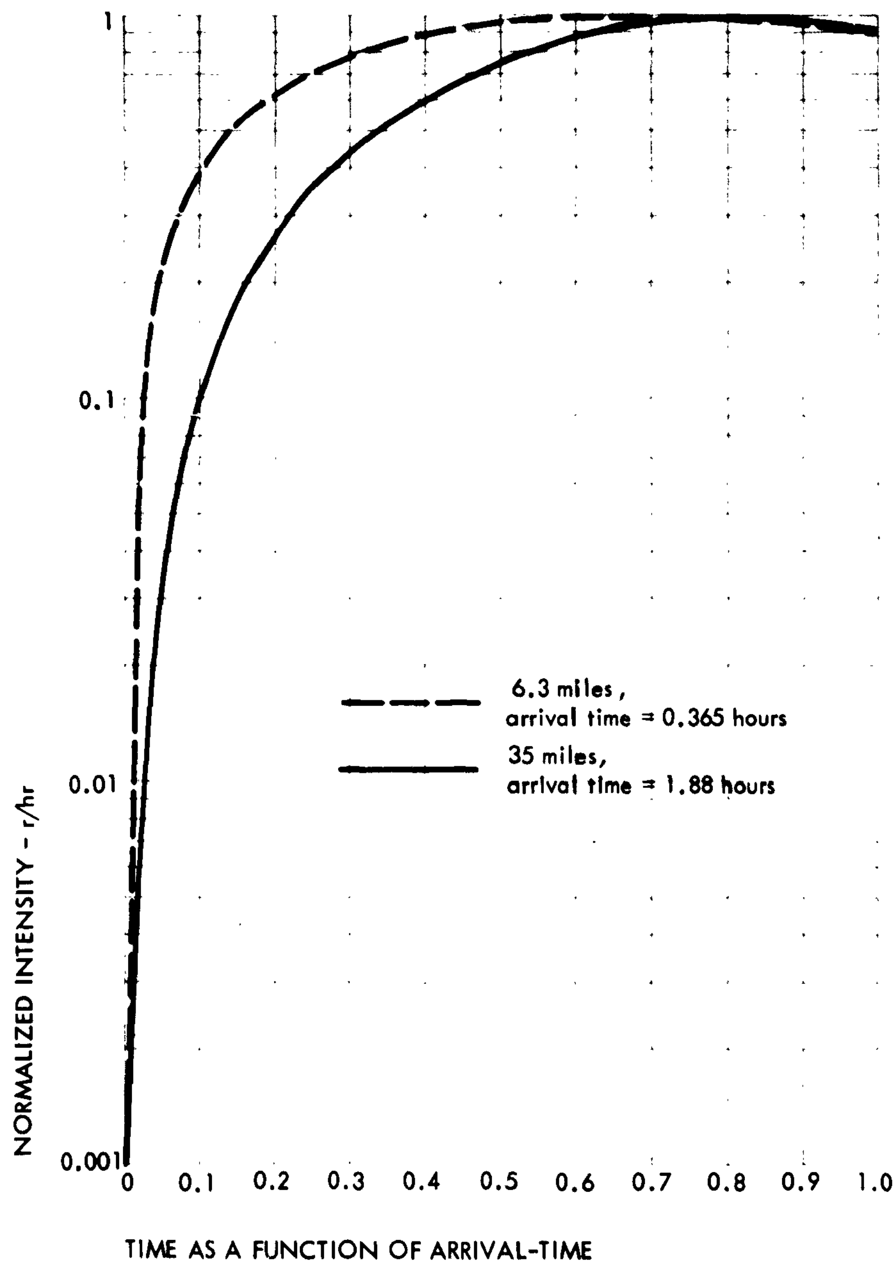
$$\text{Arrival Time} = \frac{\text{Downwind Distance} - \text{Cloud Radius}}{\text{Wind Speed}} + \text{A Constant}$$

where the constant term characterizes the arrival time at points closer to ground zero than the cloud radius. Obviously, as the downwind distance increases the factor of cloud radius becomes increasingly less important, especially for the smaller weapons. In general, arrival time becomes a simple distance-speed radio.

The time of build-up from the time of arrival to peak intensity generally is considered to be a function of arrival time. LaRiviere originally indicated that this time period might be taken as twice the time of arrival up to a maximum arrival time of 13 hours.[15] Shnider and Shapiro later suggested that to a good approximation the build-up time can be taken as equal to the time required for one-half of the stabilized cloud to pass over the point of interest.[14] The build-up characteristics depend to some extent on the radioactivity associated with various particle sizes. Because of the difference in settling rate of each size of particle, the intensity build-up function should be expected to vary from point to point downwind. Miller has examined these variations at two points downwind of a 1 MT weapon for a 15-mile-per-hour wind.[10] One point was located 6.3 miles downwind and was contaminated by particles from the stem; the second was about 35 miles downwind and received particles from the cloud alone. Both points have a standardized H+1 intensity of 2,000 roentgens per hour. The intensity variations over time at these points are summarized in Figure 24. These data have been normalized with respect to radiation intensity and show the manner in which build-up occurs for arrival times of 0.365 and 1.88 hours. As can be noted, the peak intensity for these cases occurs between about 0.7 and 0.9 times the arrival time with the time to peak generally increasing with arrival time.

Figure 24 and nearly all other data for single weapons show the build-up as a smooth function of time. In actual practice, the build-up undergoes numerous variations in slope with the intensity somewhat randomly increasing and decreasing around the basic upward trend before the final peak is reached. This fact arises because of the different falling rates of each particle size and the variation in the amount of radioactivity of the particles combined with the decay rates of all the particles which have fallen up to any given time. Micrometeorological forces, such as the effects of eddy currents and small breezes moving the particles alternately toward and away from the monitoring point, also may cause some variations.

Figure 24
NORMALIZED VARIATIONS OF THE DOSE RATE AT TWO POINTS DURING THE FALLOUT PERIOD



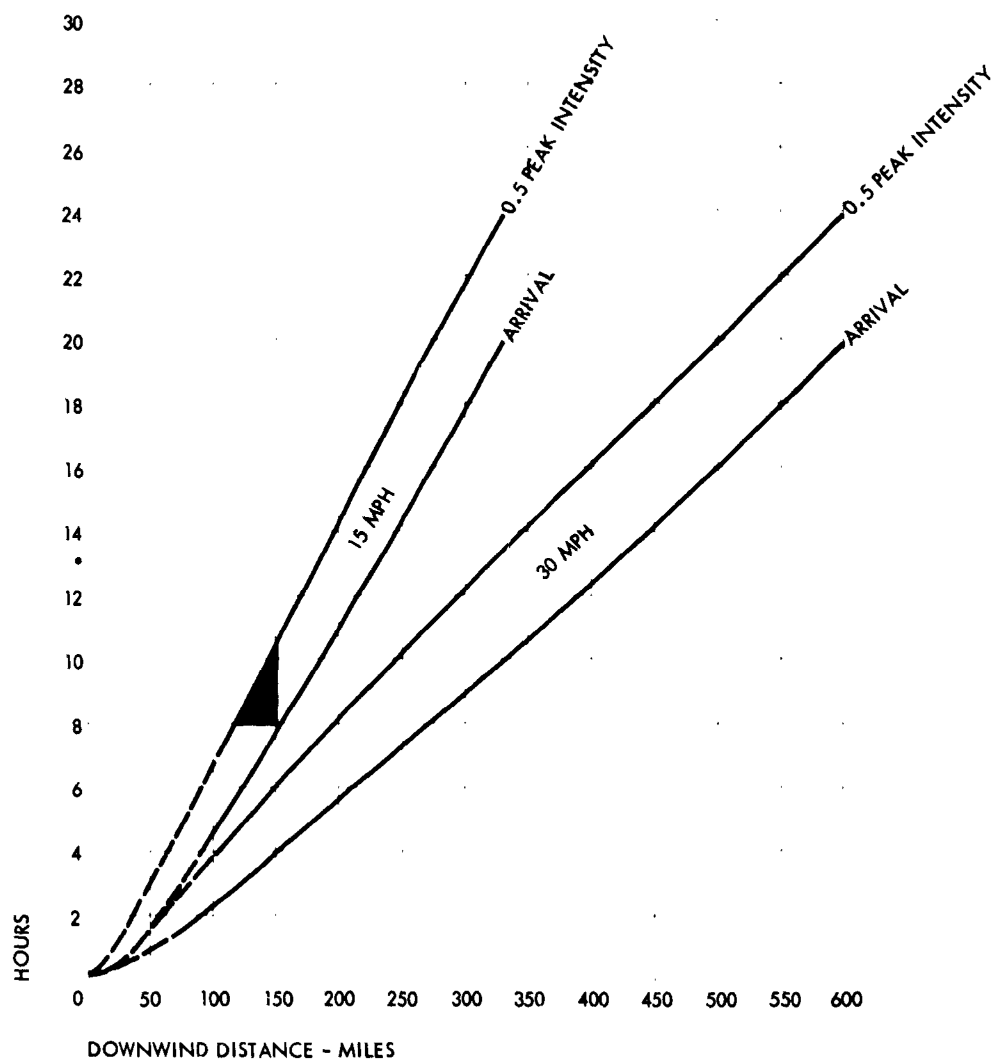
Source: C.F. Miller, Fallout and Radiological Countermeasures, volume I, Stanford Research Institute, February 1963

The build-up rates shown above provide one measure of the reporting procedures which the monitoring stations should be designed to meet. The greatest burden on the monitoring and reporting system, as shown in Figure 24, will occur during the early phases of the fallout period when the intensity is increasing at a high rate. For example, the dose rate at the cloud-contaminated point reaches one-half the maximum at 0.35 of the fallout period. The peak intensity occurs near the end of the fallout period at 0.91 of the total interval. The frequency at which stations should report during the early period tends to constrain the design of the communication system insofar as specifying the number of stations which should be linked to the command headquarters by the same circuit and the reporting time of each station. This constraint is shown in Figure 25 which illustrates, first, the arrival time for two wind speeds at various distances downwind of the ground zero for a 10 MT weapon. The arrival times near ground zero are designated by broken lines because the uncertainty exceeds that of the downwind arrival times. Points under the initial cloud may begin to receive fallout virtually simultaneously, regardless of the distance from ground zero or the wind conditions. Now, expressing the maximum build-up rate as a function of the arrival time (see Figure 24) with a nominal value of 0.35 times the arrival time for single bursts, a second curve for 0.5 of the peak intensity can be plotted for each of the arrival time curves. The difference between the curves is the expected time of maximum build-up rate at points downwind from ground zero.

The relationship of the time between time of arrival and maximum build-up rate and the station spacing can be observed. The triangle drawn on Figure 25 for the 15-mph case illustrates this situation. The time of the maximum build-up rate shown here is approximately three hours. If, for example, stations were located at spacings greater than about 45 miles in the direction in which the cloud is moving for this particular situation one row of stations would have completed their maximum rate of reporting prior to the time that the next row begins to report the presence of fallout. Generally, the time-to-peak intensity increases with distance so that the reporting sequence of the successive rows of stations tends to overlap. However, the peak to which the radiation builds up is far less than for the stations close to ground zero, so that the total number of reports is considerably less.

The ultimate test of the permissible delay in the reports of monitoring stations depends upon the ability of command to make prompt use of information as it arrives. In cases where the planning cycle requires a period of hours, the delay in station reports in the order of minutes would not appear of consequence. The cost and complexity of the communication system must be commensurate with the ability to utilize the information which it carries. The greatest requirement for speed in reporting arises from the need to provide warning. However, sequential reports from the same stations are not required to support this function but rather only the initial report of arrival at each station.

Figure 25
FALLOUT ARRIVAL AND TIMES FOR MAXIMUM BUILD-UP RATES AT DOWNWIND POINTS ALONG THE HOT LINE



A second guide to the network configuration arises from the intensities to be reported. During the build-up the minimum requirements for reporting can be associated with the intensities which mark the threshold of the next higher hazard state than previously existed. In an automatic or manual system the equipment can be designed or the personnel instructed to report by doctrine when these threshold intensities are reached. Otherwise they remain silent. The purpose of reporting these intensity thresholds is to support Administrative Command in its planning of early emergency operations and support of the military after cessation of fallout. The status of the population at that future time when these operations can be carried out is of primary importance and the threshold intensities reported during the build-up should be selected in such a way that the segments of the population in each state of risk or injury class can be estimated. In other words, planning for emergency operations must be based on estimates of future conditions which are made during the planning efforts.

The determination of the various states of risk or injury groups, in which the population will be distributed at some future time, depends upon both the time itself and the characteristics of the dose-rate over this time. These two factors taken together determine the levels of intensity associated with the hazard state thresholds reported by the monitoring stations. The question of time before initiation of emergency operations depends upon the period of fallout deposition and the planning and reaction time of the civil defense organization. Rarely can operations be expected to be initiated during the fallout event itself. The total time in which fallout is deposited depends upon the size of the attack and the time over which it extends. Fallout from single weapons could last as long as 18 to 20 hours. Overlap of fallout patterns from weapons detonated over time as indicated in Figure 7 could extend the deposition time over far longer periods. The fallout period, of course, can be expected to be different from place to place across the nation.

The planning and reaction time of the civil defense organization depends upon its over-all level of proficiency and state of readiness. If all organizational elements were able to assemble forces and otherwise reach a high state of readiness prior to the arrival of fallout, the reaction time should be considerably less than that required in circumstances where no mobilization occurred. The time of the planning and reaction cycle also depends upon the presence of other hazards in addition to fallout.

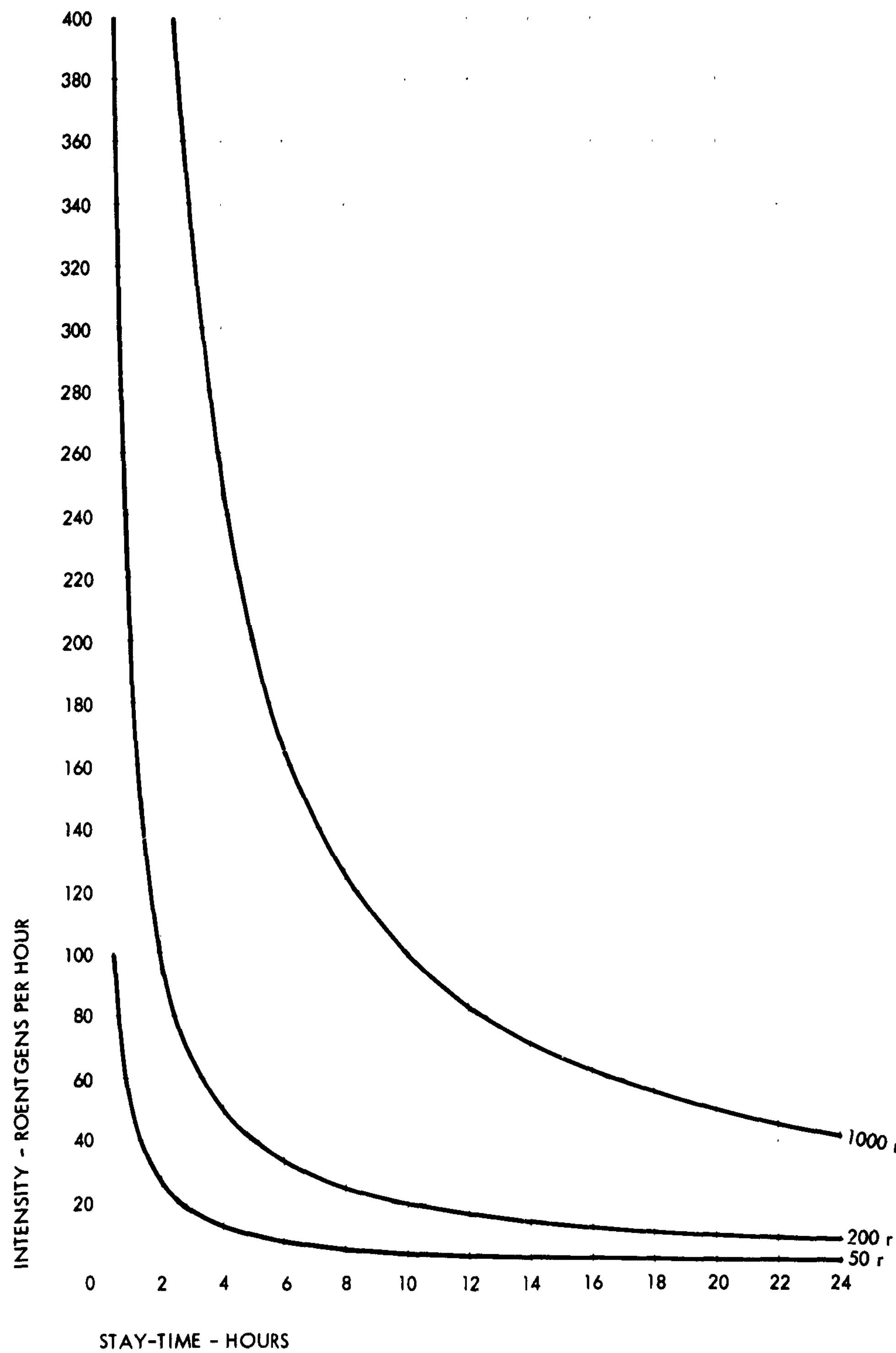
In view of these considerations, plus the virtual impossibility of predicting in any detail the fallout and associated hazard situation as it would actually develop, the minimum time before Administrative Command could initiate any coordinated operations should be expected to be in the order of not less than 24 hours. Operational Command and other local units at various places throughout the nation undoubtedly will need considerably less time, especially those in

areas of slight contamination. However, in consideration of the broader functions of Administrative Command in planning for the nation as a whole, these isolated variations tend to disappear.

The characteristics of the dose rate over the time of interest--24 hours for planning purposes here--must, of course, also be prescribed. During the intensity build-up period there is no method by which the maximum dose rate or its variation over time at a monitoring point can be predicted. Nevertheless, Administrative Command must initiate its early emergency planning and related functions without delay rather than wait until the radiological situation has reached the relatively stable decay period. Under such conditions of uncertainty the simplest and perhaps the most useful procedure to estimate the dose rate over time is to predict that the conditions observed will persist through the time of interest. Either the intensity at the time of observation or the rate of change of sequential intensity measurements could be used as the basis of a persistence prediction. Intensity persistence is perhaps more suitable for operational purposes because of its simplicity of use. Moreover, as shown in Figure 7, for points contaminated by fallout from more than one weapon at successive intervals, the tendency for persistence of intensity at some level is evident. For attacks of any appreciable magnitude, overlapping patterns materializing over time are likely to be more prevalent than single isolated patterns.

The sensitivity of the assumption of constant radiation over time to define future hazard states is shown in Figure 26. The three curves correspond to doses of 50, 200, and 1,000 roentgens--the hazard-state dose limits--which would be received from various intensities as a function of exposure time measured in hours. It is clear, for example, that for intensities less than about two roentgens the estimate of hazard state which will exist is somewhat insensitive to times of early operational significance. The hazard state will be nominal for at least the first one to two days. Similarly, intensities from about two to eight roentgens produce a noncritical hazard state for stay times up to about 24 hours. Thus, estimates of the planning and reaction time of the civil defense organizational elements can vary from about 24 to 36 hours without introducing significant errors in dose prediction. At the opposite extreme for high intensities, the estimates of hazard state over time become more critical to the time factor. However, from an operational point of view the ability of Administrative Command to bring relief to such areas three to four hours is remote indeed. Thus, whether an extreme hazard state will be reached in three hours or five hours does not appear to be significant to Administrative Command. The intermediate range presents the greatest uncertainty in estimating the hazard state since it is highly sensitive to both time and intensity. Acquisition of intensity readings at the cessation of fallout and beyond are of greatest significance in correcting earlier estimates of the hazard states formulated on a persistency basis during build-up.

Figure 26
STAY-TIMES IN A CONSTANT-INTENSITY FIELD TO RECEIVE HAZARD-STATE DOSE LIMITS



From these relationships of dose-reaction time the intensity levels associated with the hazard-state thresholds during build-up on the basis of a 24-hour persistency prediction can be defined as follows:

Hazard State	Intensity (r/hr)
Noncritical	2
Critical	8
Extreme	40

That is, during the build-up period when the intensity reaches two roentgens per hour, the station should report. A report on this intensity indicates that at the end of the 24-hour period the population in the area will have received a dose such that it passes from the nominal hazard-state to the noncritical state. Similarly, a report at eight roentgens per hour signifies that at the end of the 24-hour period the population will be in a critical state. At 40 roentgens per hour the extreme state will have been reached 24 hours later.

These reporting points apply to those segments of the population without fallout protection. Additional points of intensity clearly are desirable in order to estimate the hazard states to the population within various shelter classes. Intensity measurements of far greater magnitudes will be required. The intensities to be reported can be defined in terms of the protection factors associated with shelter classes as follows:[11]

Shelter Class	Protection Factor
A	> 1,000
B	250-1,000
C	50-250
D	10-50
E	2-10
F	< 2

Thus, with the indicated protection-factor limits, the intensity levels to be reported by a fixed monitoring system to characterize the hazard-state thresholds for shelter occupants can be defined as shown in Table XXVI.

In addition to these reporting points, a dose rate should also be reported for purposes of warning. Its magnitude likely should be in the order of 0.1-0.5 r/hr. The final choice would depend upon the sensitivity to which the monitoring stations can be designed within other system constraints.

Table XXVI

LEVELS OF HAZARD-STATE THRESHOLD INTENSITY REPORTS FOR VARIOUS SHELTER PROTECTION FACTORS
(r/hr)

	Protection Factor					
Hazard State	1	2	10	50	250	1,000
Noncritical	2 r/hr	4 r/hr	20 r/hr	100 r/hr	500 r/hr	2,000 r/hr
Critical	8	16	80	400	2,000	8,000
Extreme	40	80	400	2,000	10,000	40,000

The intensity levels which should be reported by the fixed monitoring system during build-up for assessment of the status of the nation's population is summarized in Table XXVII

Table XXVII

INTENSITY REPORTING POINTS
DURING FALLOUT BUILD-UP

0.1 r/hr	100 r/hr
2	400
4	500
8	2,000
16	8,000
20	10,000
40	40,000
80	

A total of 15 dose rates with a maximum of 40,000 r/hr are indicated in the table. The value of this maximum reading appears to be somewhat marginal in its utility. Except for extraordinarily heavy attacks the number of stations which could be expected to detect a field of this magnitude should be very low. Moreover, since the 40,000 r/hr measurement is required for estimation of the conditions within Class A shelters, it would have limited application due to the scarcity of these shelters. Because of these two conditions the maximum measurement which a fixed monitoring station can report could be reduced to the range of 10,000 r/hr. This is slightly higher than the critical hazard-state threshold of the Class A shelter and equivalent to the extreme hazard-state

threshold of the Class B shelter. The ultimate decision would rest upon the additional cost and complexity of a station to measure 40,000 r/hr versus one to detect 10,000 r/hr. If no appreciable difference in cost is involved, the higher reading station should be selected. Moreover, similar considerations of equipment design tend to apply to the lower levels of intensity reporting. Because of the imprecision to which the protection factors of shelters can be calculated as well as the large range of protection included within most shelter classes, some latitude in intensity reporting levels for the purpose of simplifying the design of monitoring and coding equipment should be permissible.

Adjustments in this reporting procedure would be required for planning and reaction times other than 24 hours over which the intensity is predicted to persist. However, as was noted from Figure 26, these times could range from about 16 to as much as 36 hours in the low dose-rate region without causing undue operationally signigicant differences in the hazard-state intensity thresholds. Moreover, if additional shelter classifications were established, such as protection factors of 100 and 500, a corresponding increase in reporting points should be made.

Reporting during Decay

Once the fallout intensity peak is reached, the situation undergoes a significant change in terms of the time scale of events, as long as fallout from other weapons does not arrive subsequently. The decay process not only extends over a far greater period of time than the build-up but is also comparatively predictable over time. Because of these differences, a corresponding change in reporting procedures is possible. Although estimates of the hazard situation during the period of build-up may be in error because of the inability to accurately estimate the intensity variations over time, planning and other command functions must be carried forward. Description of the future radiological situation, as mentioned above, can be based upon a persistency prediction. As successive intensity readings are received at the command center, appropriate revisions are made in the predicted radiological situation and the expected portions of the population at each level of risk. After the peak intensity is reached and the decay phase is entered the first comparatively firm estimate of future dose can be made. The possibility should be recognized, however, that additional contamination and subsequent peaks due to later weapons (see Figure 7) might occur.

The estimates of dose in the decay period can be made either on the basis of a persistency prediction or on the observed rate of intensity decay. In general, within the constraints of systemcomplexity and cost, the accuracy of prediction on a decay versus a persistency basis should justify the acquisition of sufficient intensity measurements to determine the decay rate. This is

particularly true in the early phases of an attack when decay is very rapid. A first approximation of the decay rate could be obtained by using the same intensity reporting system utilized during the build-up period. That is, on build-up the monitor points report at the time the dose-rate reaches the levels indicated in Table XXVII. These same intensities could be reported by the monitor points during the decay. By noting the time between reports, the decay rate at each station could be determined for use in dose prediction. These dose-rate reporting points are not uniformly spaced over the range of intensities but rather vary by factors between 1.25 and 4. Thus, use of these reported intensity levels to determine the decay rate would be more suitable for some ranges of intensity than others. For example, at equivalent rates, the time required to determine the rate of decay for a 100 r/hr field would be considerably less than the time for a 16 r/hr field. In the former, a point on the decay curve is determined at 80 r/hr, a 20 percent decay, whereas in the latter, a 50 percent intensity decay to 8 r/hr is required before the decay function can be defined.

In view of this condition additional points at which intensity should be reported during decay may be desirable. The definition of these additional levels requires consideration of two factors. The first and more significant is naturally the required increments of intensity readings to accurately determine the decay function. Second, the design of a monitoring station, including the analog to digital conversion equipment will, of necessity, increase in complexity as the number and range of intensity measurements increase. That is, in an automatic monitoring system capable of adequately supporting Administrative Command, the transmission of information appears to be best suited to a digital rather than an analog form because of considerations of signal distortion and attenuation as well as problems of station identification discussed below. Since the intensity measurement is essentially an analog function, conversion must be made to a digital format prior to transmission. In the interest of simplicity of station equipment and reduction of communication loads, it would appear suitable to avoid transmitting the actual intensity reading in roentgens per hour. Conversion could be made to a binary or similar code, using the smallest possible number of bits as the equivalent of the longer intensity reading itself. For example, 1 roentgen per hour would be transmitted as "1," 10 roentgens as "2," 100 roentgens as "3," and so forth. Obviously, transmitting a 3 requires considerably less time than transmitting 100.

The precise format of the coding and reporting is subject to numerous detail design considerations which are beyond the scope of this analysis. Typical of possible coding procedures which could be used are the binary or radix 2, the binary coded decimal, and the binary coded octal. Normally in these codes a fixed number of bits (zeros or ones) is used to represent each numerical character from zero to nine; the octal code, of course, is restricted to zero to seven. Thus, in a standard format of reporting by any of these codes,

the number of different intensity readings which can be reported increases by a factor of 10 with each increase in the number of code groups, except in the binary coded octal form where the increase is a factor of eight. This typical progression is shown below for the binary coded decimal, octal, and the excess-3 codes.

Decimal	Decimal Equivalent	Excess-3 Binary Code Equivalent	Octal Code Equivalent
0	0000	0011	000
8	1000	1011	001 000
10	0001 0000	0100 0011	001 010
64	0110 0100	1001 0111	001 000 000
100	0001 0000 0000	0100 0011 0011	001 100 100

The impact on system design and reporting procedures of these forms of coding is that additional measurements can be obtained without additional load on most parts of the communication and monitoring system. For example, if the binary code is used and seven measurements are required, three additional measurements can be obtained without additional load. The system, of course, could utilize other codes wherein the relationship between the number of bits and the decimal equivalent is different than shown here, but the variation remains in terms of discrete levels rather than a smooth continuum.*

It should be noted, however, that in considering the message load on the communication and processing system, the portion of a message from a monitoring station to the command post which actually contains the radiation information is small with respect to the total message length. In any reporting system the message from a monitoring point must consist of at least station identification and the radiation data. Other information, such as time and date of report, may or may not be desirable.

In a digital system it is likely that several pulses for synchronizing, parity of error checks, and perhaps beginning- and end-of-message pulses will be necessary. For example, in a 1,200-station system using the binary coded decimal, the station identifier would require 16 bits and the miscellaneous synchronizing and other pulses may possibly number about four. The message length, exclusive of radiation information, would be 20 bits. If ten different intensity measurements were desired, using the binary coded decimal, merely four additional bits would be added to the message for a total of 24 bits. At the expense of adding four more bits the number of intensity measurements

* In general, for a binary system the number of intensities which can be reported for a given code is 2^n, where n is the number of bits.

could be increased to 100 for a total message length of 28 bits. In this case the radiation information is still less than one-half of the total message length.

Because of these coding constraints, some freedom exists in specifying the increments at which radiation information should be transmitted by a monitoring station. A total of 15 dose rates is indicated in Table XXVII. These could be readily handled by a 4-bit code in perhaps a binary coded decimal form. However, by the addition of one bit the number of intensity measurements could be increased to 32 so that a higher level of accuracy in decay rate determined could be achieved. The need for smaller increments of intensity measurements tends to lie in the lower ranges of the monitoring scale. For example, with the conventional assumption that intensity decays by a factor of ten with a factor of seven increase in time, let it be assumed that arrival and deposition time at a station is in the order of seven hours. Under this condition the 14 intensity reporting points (excluding 0.1 r/hr) shown above for build-up have corresponding intensities two days later as shown below.

0.2 r/hr	2	40	1,000
0.4	4	50	4,000
0.8	8	200	
1.6	10	800	

As can be noted, the high intensities (such as 1,000 r/hr) decay into low levels previously established for build-up reporting. On the other hand, the very low dose rates decay to levels which are not of great operational significance to Administrative Command in the early periods of attack. It would appear doubtful, for example, that reports of intensity levels at 0.2 r/hr would be of great value to Administrative Command except for warning. Thus, the number of new points established for reporting on decay over those for reporting build-up is small. The intensity levels shown above can be merged with those for the build-up to indicate the total number of station dose-rate reporting points as shown in Table XXVIII.

A total of 23 reporting points is indicated. The difference between two successive points has been decreased to a maximum of a factor of two, except for the marginal 40,000 r/hr reporting point. These smaller differences should permit a quicker, more accurate definition of the decay rate. It should be noted that with the use of a five-bit code for transmission of these intensities, an additional nine could be included without any increase in communication loads. Such an addition, however, would tend to increase the complexity of an automatic monitoring station. The selection of these points should be directed toward reduction of the increments between reporting levels in the middle ranges--probably between the dose-rates of 50 and 500 r/hr.

Table XXVIII

TYPICAL INTENSITY REPORTING POINTS DURING DECAY

0.1 r/hr	40 r/hr	8,000 r/hr
0.4	50	10,000
0.8	80	40,000
1.6	100	
2	200	
4	400	
8	500	
10	1,000	
16	2,000	
20	4,000	

If stations have the capability of monitoring and reporting these dose rates during decay, the possibility certainly would exist for reporting them during build-up as well. The build-up reporting levels were developed to provide an adequate description of the radiological situation with a minimum of information. However, if system cost and complexity are not inordinately increased, there would appear to be no compelling reason to prevent the report of these dose-rate levels on build-up as well.

Processing and Analysis at Administrative Command

The radiological information received at Administrative Command from the monitoring system must be processed and properly summarized for presentation to the command personnel as rapidly as possible after its receipt. The radiological situation will be in a constant state of change especially in the early periods after the start of the war. Intelligence processing facilities, therefore, must be able to operate in real time with a minimum of delay between the receipt of raw radiation information and its analysis for command personnel. The basic actions which must be executed include the following:

1. Receive and store radiation reports from all monitoring stations; including the time of reporting.

2. Determine radiation decay rates from monitoring station reports.

3. Estimate the exterior and shelter hazard states which will exist in each station area as a function of various stay times, based on both estimated and measured decay rates.

4. Develop estimates of casualties and the population at risk in the nation for selected shelter situations.

5. Estimate hazard states as they apply to forces re-entering contaminated areas, especially those areas highly critical to early survival and support of the military in continuing the war.

6. Predict fallout arrivals and warn local Operational Command.

The method in which these operations are carried forward depends to a large extent upon the number of monitoring stations reporting to the command center. The greater the number of monitoring stations, the greater will be the requirement for automated procedures. Moreover, as the number of critical resources in which Administrative Command has an interest increases, the need for automatic facilities will correspondingly increase. The design of these facilities should stem from the common basis on which the critical resources of the nation have been aggregated. As noted earlier, the aggregate base also defines the spacing of the monitoring stations.

The general procedure for processing and analysis of radiological information at command headquarters consists of the estimation of the hazard state which will exist in each unit area of aggregation for each resource of interest for various times of exit or re-entry. The mathematical computations required to make these estimations are relatively elementary in form. A simple but fast computational device appears to be indicated.

The requirements for information storage are likely to be large with an accompanying need for rapid store-and-retrieve capability. The characteristics of each class of resource of interest to command will require storage space equivalent to the total number of units of aggregation. For example, if the basis of aggregation is a 50-mile square, each resource class would require a storage matrix of about 1,200 cells; a 30-mile spacing would require approximately 3,300 cells. In the case of population in different shelter conditions, one storage matrix would be required for each condition. It is readily apparent that a large total storage capacity will be required by Administrative Command for the basic national resources of interest, especially those which are distributed throughout the nation.

Associated with each resource category there must be an additional group of storage matrices in which the results of damage assessment, casualty estimates, and any other analyses are stored. For example, since estimates of the hazard state to population in an area is a function of stay time, a full storage matrix will be required for each stay time desired; moreover, if it is desired to measure hazard state as a function of shelter protection factors, as well as stay time, an additional storage matrix will be required for each of these conditions.

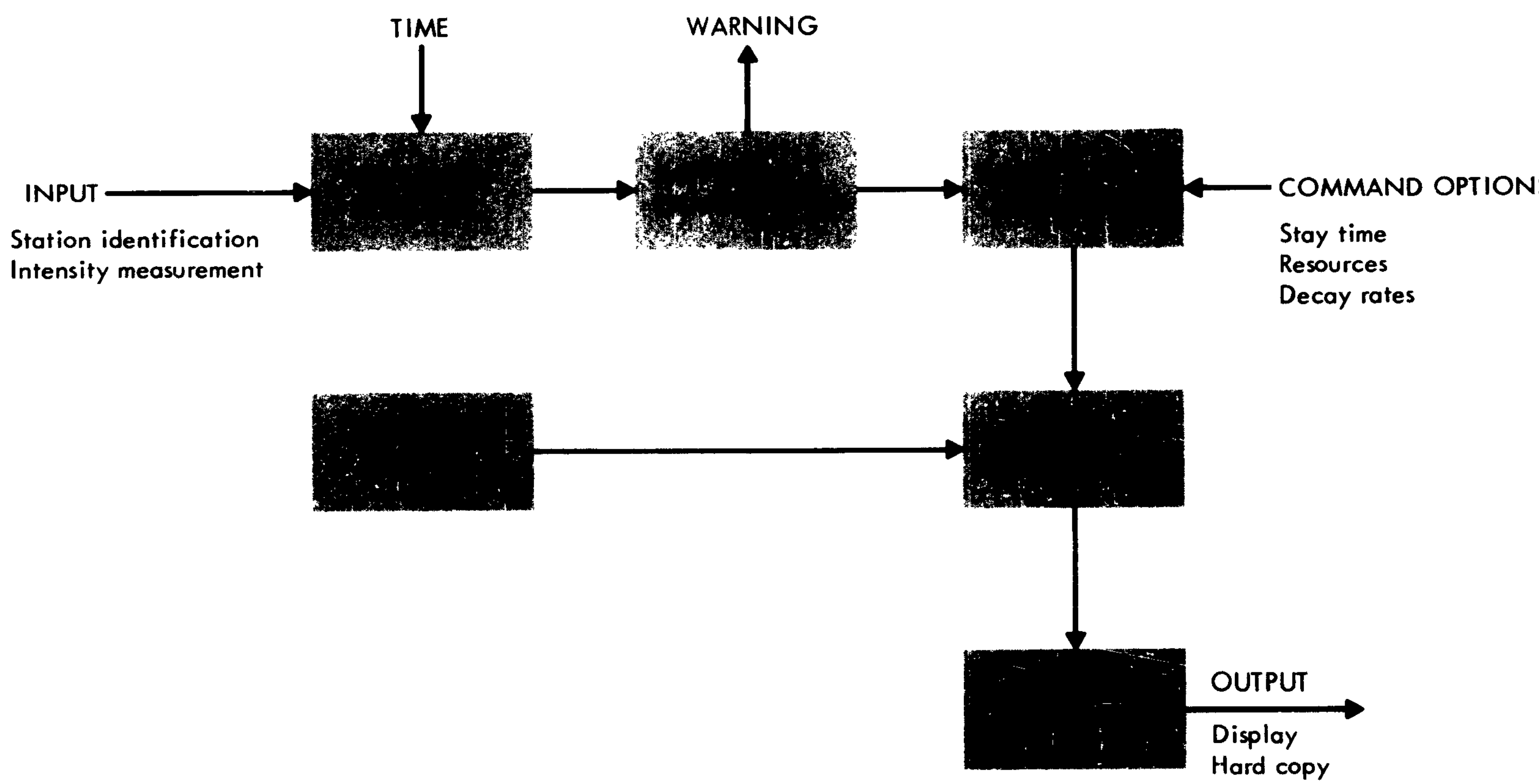
In the early phases of the war until the fallout has stopped, the estimates of casualties and radiation hazards will undergo constant change. For this reason it appears desirable that storage facilities be sufficiently large for retaining more than one set of situation estimates. That is, rather than replace or destroy a set of situation estimates each time a revised radiation report is received, the old set should be held for checking consistency and reasonableness of subsequent intensity reports and situation estimates.

These analysis and processing procedures would apply to both an automatic and a manual monitoring system. In an automatic system reports would be received from each monitoring station in digital form and entered directly into the processing facilities. In a manual monitoring system reports from monitoring stations would require manual encoding, probably by punch cards, at command headquarters before entry into the automated facilities. The fully automatic system should also be capable of manual entry so that status reports and associated information from Operational Commands received by other modes of communication can be processed rapidly and in the same system as earlier reports.

The basic processing and analysis operations are summarized in Figure 27. The monitoring station identifier and the intensity measurement are received at the command post and stored in the raw data storage. The time at which the report is received is also entered. Recording the time at the command post rather than at the monitoring station would reduce the message length to the minimum and preclude the need for clocks in the stations. Each monitoring station may have a unique storage location in the system, so that the station identifier could be removed at this point. Conversion can be made from the reporting code to intensity levels as well.

The time-intensity information of each report should first be examined to determine if the reading is higher or lower than the previous measurement. For the first reports after the war starts the increase from zero intensity will provide warning information for areas not yet affected by fallout. These data when combined with other information, such as detonation reports and wind conditions, should enable command to transmit warning to lower commands for propagation to the general population. Comparison of the raw data will also indicate the procedure to be used in computation of the hazard states. That is, if the intensity is still increasing the procedures can be based upon a persistency basis; whereas, when sequential intensity readings decrease the calculation on a decay basis is indicated. At this time either the command could begin to interrogate the monitoring stations for readings to establish the decay function, or the stations could continue to report automatically.

Figure 27
GENERALIZED SYSTEM OF PROCESSING RADIOLOGICAL INFORMATION AT ADMINISTRATIVE COMMAND HEADQUARTERS



The hazard-state computation procedures should be flexible and subject to the option of command in specifying the stay times, persistency or decay rates to use, and similar parameters. These computations must be made for each monitoring station area.

Subsequent to the hazard-state computation the assessment of the state of the resources of interest can be completed in a straight-forward manner. The procedure should be similar to that which has been in long use by the National Resource Evaluation Center and other installations. The assessment results must be stored and made available to the command personnel.

The procedures and techniques for presenting and displaying the final situation estimates and radiation hazard conditions throughout the nation can take a wide variety of forms. Basically, these are likely to consist of hard copy print-out for headquarters staff personnel and a geographically oriented display device for the highest echelon. The primary content of these data should be in the form of a status-of-forces report and include casualty estimates and indications of the operability of the critical resources in the nation. Intensity reports, decay measurements, and perhaps similar information, such as indications of fission ratios, should be available on demand and may be of value for later staff use. Because decisions must be made on the basis of the effect of radiation on resources and not on radiation information alone, there appears to be slight need, except in detailed print-out form, for presentation of raw radiation measurements.

The total computational and storage capability required to carry out this process is directly related to both the number of monitoring stations and the number of resources of interest. In broad terms the capacities may be as follows for a system with stations at 50-mile spacings.

Raw data storage	
Capacity to store three sequential intensity measurements and times	3,600 cells
Raw data examination	
Working storage to compare intensity matrices	1,200 cells
Hazard state computation working storage	1,200 cell multiples
Resource storage	
Population in open and shelter classes A-F	8,400 cells

Manufacturing plants	1,200 cell multiples
Other classes	1,200 cell multiples
Assessment storage	9,600 cells and 1,200 cell multiples
Assessment computation working storage	1,200 cell multiples

The total storage capacity for this situation is approximately 25,000 cells or computer words. This is of course based on the assumption that resources of interest are located in every resource square, which may not be the case. Nevertheless, it is clear that the requirements for storage capacity will be large, and, in view of the mass of information to be processed, the storage and retrieval times of the facilities must be small.

As discussed earlier the computational and assessment procedures at command are based on the condition that the free field intensity measured by a monitoring station characterizes the hazard state throughout the entire area assigned to the station as illustrated in Figure 6. Other types of computational procedures have been suggested. Perhaps the most prominent has been to compute, or draw subjectively, either iso-intensity or iso-dose contours based upon the monitoring station readings. Accurate representation of the fallout situation throughout the nation by this technique does not appear operationally feasible for two primary reasons.

First, the process of describing a field over a region from a grid of fixed readings generally involves the process of interpolation, least-square curve fitting, and similar operations. The space intervals at which these operations are carried forward, as well as the spacing of the monitoring points, normally are established jointly by the complexity of the field and the desired accuracy of the information. Basically, these are established by experience in measuring the field and developing contours repeatedly. Essentially through a trial and error process, a statistical base and operational experience is developed to guide and constrain the procedures by which the contours can be calculated. Obviously, there is no such statistical base to guide the construction of iso-intensity contours to describe a national fallout pattern. Thus, the process is of extremely doubtful feasibility.

The second difficulty arises from the nature of the information to be processed and the time required for processing. During the fallout period the radiological situation is constantly changing. For single weapons the intensity levels at the monitoring stations rise rapidly, reach a peak, and then begin to decay. At stations with pattern overlap the conditions are far more complex.

Each station likely will have a unique intensity history. During the decay period the age of the fallout material at the monitoring stations will have wide variations, each with its own decay properties. Accurate correction of the fallout material to H+1 levels does not appear possible. The task of preparing iso-intensity contours under these conditions appears out of the question. The contours, moreover, would tend to have no meaning for immediate planning because of the varying age of the materials throughout the area. That is, a 10-roentgen per hour contour at two days would probably not have the same shape five days later at a lower intensity. Thus, for example, estimation of dose within the contour would be in error by unknown amounts.

In addition, the computational time required to develop contour plots tends to be excessive when accuracy is sought. For example, automatic computation of contou.. s representing barotropic fields requires 1.5 hours of computation time to handle reports of 500 stations.[16] Computation cannot be started until all reports have been received. In the case of fallout contour mapping, each time a new report received from a monitoring station the computations should be started again. Thus, in the early build-up periods it is doubtful if any contour maps could be developed in time to be of assistance in early recovery planning.

Costs of Fixed Monitoring Systems

The costs of fixed monitoring systems are directly related to the number of reporting stations in the system. Costs have been estimated for systems of stations separated by 70, 50, and 30 miles on a rectangular grid for both manual and automatic systems. The initial unit investment and annual operating costs of the monitoring stations are summarized in Table XXIX for the special-structure manual stations and in Table XXX for the automatic facility.*

In the manual system the assumption is made that the monitoring station is located near a 24-hour manned installation, such as a police or fire station, and that the police and firemen are trained to operate the station. Normally the monitoring station is deserted; but, upon warning, at least one man will go to the monitoring station and remain until instructed to do otherwise. The monitoring station, therefore, must be a well shielded structure and have food and water for a protracted stay.

* For the unit cost of a monitoring station operated from within a Class A Shelter, see Table XXXIX.

Table XXIX

UNIT COST OF A FIXED MANUAL MONITORING STATION

	Cost
Initial Investment	
Reinforced concrete shelter, protection factor of 2,000[a]	$2,075
Land	0
Telephone facilities, installed	200
Electric power facilities, installed	200
Monitoring equipment, installed[b]	500
Equipment, furniture, sanitation, food, etc.	150
Training	160
Total	$3,285
Total rounded	$3,300
Annual Operating	
Instrument maintenance @ 5% of initial cost	25
Telephone @ $5/month	60
Inspection, 12 times per year	24
Total	$ 109
Total rounded	$ 110

a. Low Cost Family Shelters, prepared for Office of Civil Defense, by Stanford Research Institute, Menlo Park, October 1961.

b. Community Level Radiation Monitoring System Cost Analysis Study, prepared for Office of Civil Defense, by Dresser Electronics, SIE Division, Houston, Texas, July 1962.

Source: Derived by Stanford Research Institute.

Table XXX

UNIT COST OF A FIXED AUTOMATIC MONITORING STATION

	Cost
Initial Investment	
Instrument housing, galvanized corrugated steel culvert, 3' diameter, 4' high, buried	$ 58
Land	0
Telephone facilities, installed	200
Electric power facilities, installed	200
Monitoring equipment[a]	500
Coding and conversion equipment[a]	500
Total	$1,458
Total rounded	1,460
Annual Operating	
Instrument maintenance @ 5% of initial cost	50
Telephone @ $5/month	60
Inspection, 12 times per year	48
Total	$ 158
Total rounded	160

a. Community Level Radiation Monitoring System Cost Analysis Study, prepared for Office of Civil Defense by Dresser Electronics, SIE Division, Houston, Texas, July 1962.

Source: Derived by Stanford Research Institute.

Telephone and power lines to the station are assumed to be buried. The telephone lines connect the station either to the 24-hour manned installation or to the nearest telephone exchange. Power facilities are included for maintenance and test operation of the equipment and for battery charging units if wet cells rather than dry cells are used for equipment operation.

The cost of the monitoring equipment has been estimated at $500. Because the station may be required to detect intensities in the range of 10 to 40 kiloroentgens per hour, the standard civil defense instruments would not be appropriate. However, use of smaller intensity meters with shielded probes may be possible, in which case the V-711 or V-717, for example, would be applicable. If areas suitable for the installation of monitoring equipment are near Class A shelters, remote-reading instruments could most likely be used. In this case the costs of the structure and the necessary furnishings, sanitation facilities, and related items would be essentially nil as far as it affects the monitoring system. Moreover, the initial costs for installation of power and telephone equipment should be substantially lower. Under these conditions the unit costs would be comparable to the manned stations to support operational command and are shown in Table XXXIX.

The unit costs of the automatic and special-structure manual stations for a national monitoring system with the three station spacings of 70, 50, and 30 miles, uniformly covering the nation, are summarized in Table XXXI on a national and regional basis.

The critical factor in developing the cost of any system of this type is the communication network required to support the system. A number of different network configurations or operational procedures appear possible. Three of these are shown here. First, all monitoring points can be linked to command headquarters by engineered private-line facilities which are leased full-time. Operational costs of this system, however, may be prohibitive. Second, monitoring circuits and routings can be designated for the system but not activated or called up until needed. This procedure obviously involves full cooperation of the telephone industry and entails the risk of not having the circuits activated early in the emergency period. Third, the monitoring stations could simply utilize the existing dial system, with the proviso that all necessary circuits and exchanges be coordinated with line-load control procedures. This procedure has many obvious risks. Requirements for any system under consideration should include a high capability to survive an attack by the use of hardened facilities and rapid rerouting procedures.

The three systems discussed above, as well as other alternatives, should be explored to determine their relative feasibility. For cost purposes here the three systems will be treated as follows. In the case of full period leased circuits, a cost of $4.00 per mile per month is typical for most telephone

Table XXXI

INITIAL INVESTMENT AND ANNUAL OPERATING COSTS OF FIXED MONITORING STATIONS FOR THREE STATION SPACINGS

COST CATEGORY	OCD REGIONS 1	2	3	4	5	6	7	8	TOTAL
70-MILE SPACING									
Initial Investment									
Manual	89,100	138,600	221,100	194,700	376,200	425,700	306,900	260,700	2,013,000
Automatic	39,420	61,320	97,820	86,140	166,440	188,340	135,780	115,340	890,600
Annual Operating									
Manual	2,970	4,620	7,370	6,490	12,540	14,190	10,230	8,690	67,100
Automatic	4,320	6,720	10,720	9,440	18,240	20,640	14,880	12,640	97,600
50-MILE SPACING									
Initial Investment									
Manual	158,400	297,000	422,400	382,800	712,800	864,600	594,000	528,000	3,960,000
Automatic	70,080	131,400	186,880	169,360	315,360	382,520	262,800	233,600	1,752,000
Annual Operating									
Manual	5,280	9,900	14,080	12,760	23,760	28,820	19,800	17,600	132,000
Automatic	7,680	14,400	20,480	18,560	34,560	41,920	28,800	25,600	192,000
30-MILE SPACING									
Initial Investment									
Manual	435,600	772,200	1,168,200	1,108,800	2,059,200	2,376,000	1,663,200	1,366,200	10,949,400
Automatic	192,720	341,640	516,840	490,560	911,040	1,051,200	735,840	604,440	4,844,300
Annual Operating									
Manual	14,520	25,740	38,940	36,960	68,640	79,200	55,440	45,540	365,000
Automatic	21,120	37,440	56,640	53,760	99,840	115,200	80,640	66,240	530,900

utilities in the nation. Local variations do exist, and the ultimate cost can be determined only by detailed review of the rate structure of each utility. Normally, however, the cost variation should not be expected to be more than about $0.50 either side of the $4.00 average tariff. Few if any initial costs are included in this charge schedule which is applicable to conventional unhardened circuits. The additional costs which may be encountered for hardening all or selected facilities have not been investigated.

The cost of the second alternative would probably consist of charges for rapid switching and other associated equipment necessary to activate the monitoring circuits. Such charges cannot be readily determined because the circuit routings and engineering design of the system must first be developed. The charges, however, would likely be accrued as a function of the number of exchanges through which the circuits must pass. A rough approximation might equate the cost of the system to the cost of bell-and-light warning facilities furnished by most telephone companies at an installation cost of $100 per station and an annual rental of $60. No costs are imputed for the use of the network during the war.

The cost of the third alternative includes only the drop to the monitoring station at $60 per year. No long lines circuit charges are applicable.

The configuration of the network can influence the annual costs of the system to an extremely significant degree. Because of considerations of communication system vulnerability, every monitoring station should have insofar as possible a physically independent circuit linking it to the command headquarters. Undoubtedly, some circuit grouping will be necessary where the lines converge at the command post, but this should be avoided whenever possible. The general principle can be established, however, that as the number of monitoring stations increases or as the spacing decreases, the degree to which the circuits can be bundled can be increased correspondingly. That is, with a small number of widely spaced stations the value of the data from each station is of considerably more significance than in a system which has a large number of very closely spaced stations

Thus, for purposes here, the costs of the communication network to link the stations to the command headquarters are based on the following relationship. Monitoring stations spaced at intervals of 70 miles cover an area of 4,900 square miles Because of the small number of stations each is linked to the command post by a circuit totally independent of all other monitoring stations. Stations at 50-mile intervals cover an area of 2,500 square miles or two per 5,000 square miles and are linked together in a common circuit to the command post. In the 30-mile spaced system each station covers 900 square miles; consequently, six stations for a total area of 5,400 square miles are linked together on a common reporting circuit. Therefore, when one reporting circuit

is lost due to direct weapon effects or other causes, radiological reports are interrupted from approximately 5,000 square miles, regardless of station spacing. Finally, in all cases, the monitoring stations within each existing civil defense region are assumed to be linked to the national headquarters via the regional headquarters which act as the final bundling point between the monitoring stations and national headquarters.

Under these assumptions, the cost of full-period leased communication facilities to support the national monitoring systems are shown in Table XXXII. These monthly charges vary by about 20 percent from the 30- to the 70-mile grid. Under the interconnection scheme indicated above this small variation is to be expected. Of course, if all monitoring stations for all grid spacings were to be individually connected to the regional or the national command posts the cost difference would be significant indeed.

The initial investment and monthly operating costs for the communication network utilizing pre-emptive or on-call circuits is summarized in Table XXXIII. Costs for the totally dialed communication system are nil for all practical purposes.

These unit costs can be combined to illustrate the total system costs for various equipment and communication configurations. The summary costs of the national system for manual operation are shown in Table XXXIV, and the costs associated with the automatic facility are illustrated in Table XXXV. In both tables, the costs are shown for three station spacing grids and for three communication system operating procedures.

Clearly, the most significant variable in the cost of a system is that attributable to the annual operating cost of the communication system. The use of full-period leased facilities as compared to other communication methods increases the operating cost by a factor of 200 to 300. A cost differential of this magnitude clearly invites detailed investigation of alternative solutions to the communication problem. The costs of all other components of the system become practically insignificant in comparison to the communication charges.

A fixed monitoring system of somewhat reduced area of coverage and correspondingly reduced costs could be considered. This system could be designed to monitor the geographical areas in which critical resources are located, as well as the areas contiguous to them. Figure 23 indicated the location of typical critical resources aggregated on a one-degree area basis. Using these areas as reference, a fixed monitoring system could be established as shown in Figure 28. A monitoring station would be established in each aggregate area containing one or more critical resources, as indicated by the large circle, along with all surrounding areas as shown by a small circle.

Figure 28
MONITORING-STATION CONFIGURATION FOR CRITICAL RESOURCES ONLY

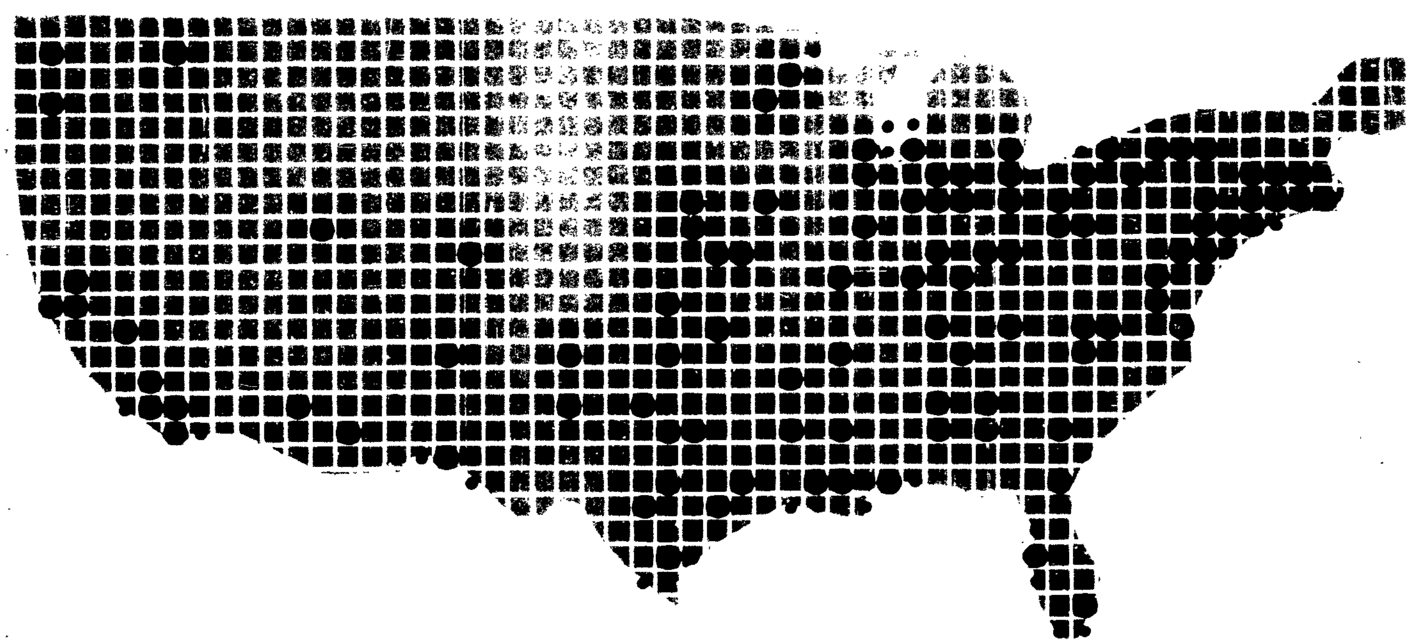


Table XXXII

MONTHLY RENTAL CHARGES FOR FULL-PERIOD ENGINEERED PRIVATE LINES AT $4.00 PER MILE PER MONTH

	Station Spacing								
	70-Mile			50-Mile			30-Mile		
Region	Stations to Region	Region to National	Total	Stations to Region	Region to National	Total	Stations to Region	Region to National	Total
1	$ 21,800	$ 1,600	$ 23,400	$ 22,600	$ 1,600	$ 24,200	$ 27,500	$ 1,600	$ 29,100
2	40,400	200	40,600	54,400	200	54,600	60,000	200	60,200
3	77,700	2,800	80,500	84,400	2,800	87,200	92,300	2,800	95,100
4	76,400	2,000	78,400	85,700	2,000	87,700	101,000	2,000	103,000
5	147,300	4,900	152,200	155,100	4,900	160,000	182,500	4,900	187,400
6	209,000	5,900	214,900	226,600	5,900	232,500	245,900	5,900	251,800
7	165,500	9,800	175,300	174,800	9,800	184,600	194,800	9,800	204,600
8	138,300	9,300	147,600	144,400	9,300	153,700	150,800	9,300	160,100
Total	$876,400	$36,500	$912,900	$948,000	$36,500	$984,500	$1,054,800	$36,500	$1,091,300

Source: Stanford Research Institute

Table XXXIII

INITIAL INVESTMENT AND MONTHLY OPERATING COSTS FOR PRE-EMPTIVE CIRCUITS

	Station Spacing					
	70-Mile		50-Mile		30-Mile	
Region	Initial Invest-ment	Monthly Operation	Initial Invest-ment	Monthly Operation	Initial Invest-ment	Monthly Operation
1	$ 2,700	$ 1,300	$ 4,800	$ 2,400	$ 13,200	$ 6,600
2	4,200	2,100	9,000	4,500	23,400	11,700
3	6,700	3,350	12,800	6,400	35,400	17,700
4	5,900	2,950	11,600	5,800	33,600	16,800
5	11,400	5,700	21,600	10,800	62,400	31,200
6	12,900	6,450	26,200	13,100	72,000	36,000
7	9,300	4,650	18,000	9,000	50,400	25,200
8	7,900	3,950	16,000	8,000	41,400	20,700
Total	$61,000	$30,450	$120,000	$60,000	$331,800	$165,900

Source: Stanford Research Institute.

Table XXXIV

SUMMARY OF INITIAL INVESTMENT AND ANNUAL OPERATING COSTS OF MANUAL FIXED MONITORING SYSTEMS

	Station Spacing		
	70-Mile	50-Mile	30-Mile
Full-Period Leased			
Initial shelter investment	$ 2,013,000	$ 3,960,000	$10,949,400
Annual operating costs			
Monitoring station	67,100	132,000	365,000
Communication	10,954,800	11,814,000	13,095,600
Total	$11,021,900	$11,946,000	$13,460,600
Pre-Emptive Circuits			
Initial shelter investment			
Monitoring station	2,013,000	3,960,000	10,949,400
Communication	61,000	120,000	331,800
Total	$ 2,074,000	$ 4,080,000	$11,281,200
Annual operating costs			
Monitoring station	67,100	132,000	365,000
Communication	365,400	720,000	1,990,800
Total	$ 432,500	$ 852,000	$ 2,355,800
Dial System			
Initial shelter investment	2,013,000	3,960,000	10,949,400
Annual operating costs			
Monitoring station	67,100	132,000	365,000
Communication	0	0	0
Total	$ 67,100	$ 132,000	$ 365,000

Source: Stanford Research Institute

Table XXXV

SUMMARY OF INITIAL INVESTMENT AND ANNUAL OPERATING COSTS OF FIXED AUTOMATIC MONITORING SYSTEMS

	Station Spacing		
	70-Mile	50-Mile	30-Mile
Full-Period Leased Circuits			
Initial shelter investment	$ 890,600	$ 1,752,000	$ 4,844,300
Annual operating costs			
Monitoring station	97,600	192,000	530,900
Communication	10,954,800	11,814,000	13,095,600
Total	$11,052,400	$12,006,000	$13,626,500
Pre-Emptive Circuits			
Initial shelter investment			
Monitoring station	890,600	1,752,000	4,844,300
Communication	61,000	120,000	331,800
Total	$ 951,600	$ 1,872,000	$ 5,176,100
Annual operating costs			
Monitoring station	97,600	192,000	530,900
Communication	365,400	720,000	1,990,800
Total	$ 463,000	$ 912,000	$ 2,521,700
Dial System			
Initial shelter investment	890,600	1,752,000	4,844,300
Annual operating costs			
Monitoring station	97,600	192,000	530,900
Communication	0	0	0
Total	$ 97,600	$ 192,000	$ 530,900

Source: Stanford Research Institute

A pattern of this configuration could be regarded as either the first phase of a nationwide system or the complete system for very critical resources. Perhaps the major disadvantage of restricting the coverage to these areas only is that the capability of providing fallout warning is severely reduced for some areas in the nation. This would be especially true in the Midwest for fallout moving in an easterly direction from detonations further west. The coverage in the eastern portions of the nation, however, is almost the same density as that which would be provided by an evenly spaced grid.

Approximately 470 monitoring stations would be required for this coverage. The costs of the system consequently are considerably less than for those previously discussed. The costs of full-period engineered circuits for this system are summarized in Table XXXVI on a unit-cost basis of $ 4.00 per mile per month. The costs from the regional headquarters to the national command post are the same shown previously for the regularly spaced systems. Each of the monitoring stations in this system is assumed to be individually linked to its respective regional headquarters.

Table XXXVI

COSTS FOR FULL-PERIOD ENGINEERED CIRCUITS OF A CRITICAL-RESOURCE MONITORING SYSTEM

Region	Intra-region	Region to National	Total Monthly	Total Annual
1	$ 25,600	$ 1,600	$ 27,200	$ 326,400
2	71,200	200	71,400	856,800
3	94,400	2,800	97,200	1,166,400
4	63,400	2,000	65,400	784,800
5	107,700	4,900	112,600	1,351,200
6	70,700	5,900	76,600	919,200
7	88,000	9,800	97,800	1,173,600
8	14,700	9,300	24,000	288,000
Total	$535,700	$36,500	$572,200	$6,866,400

The total costs for both manual and automatic operation of this system are shown in Table XXXVII. The costs of communication, of course, still represent the bulk of the system costs. In comparison to the regularly spaced grid system, the greatest cost reduction naturally occurs in the western regions of the nation, where fewer critical resources are located. Costs in the east are comparable.

The costs of equipment at command headquarters are difficult to impute. The facilities to process radiological information must be considered as merely one part of a larger complex to support the other functions of command. Automatic and manual facilities likely will be required for estimates of direct weapon effects, resource allocation, analysis of status-of-forces reports, and a wide range of other responsibilities. Multiple-use equipment should be utilized whenever possible and their costs should be allocated among the various operational uses to which they are put. Based upon the estimated required capacity for information storage and processing indicated previously (about 25,000-30,000 cells), the data processing facilities to support a monitoring system should be in the range of $ 1 million to $ 1.5 million.

It should be noted that these estimated costs do not include research and development expenditures which may be required for some elements of a system. Past and current civil defense programs have produced a wide range of instrument designs and techniques for data processing and other operations which may have direct application to fixed monitoring systems. Only a more detailed system design will disclose the degree to which such application is possible.

Table XXXVII

SUMMARY OF INITIAL INVESTMENT AND ANNUAL OPERATING COSTS OF A CRITICAL-RESOURCE MONITORING SYSTEM

	OCD Region								Total
	1	2	3	4	5	6	7	8	
Manual System									
Initial investment	$108,900	$207,900	$ 297,000	$194,700	$ 353,100	$132,000	$ 174,900	$ 75,900	$1,544,400
Annual operating									
Station	3,630	6,930	9,900	6,490	11,770	4,400	5,830	2,530	51,480
Communication	326,400	856,800	1,166,400	784,800	1,351,200	919,200	1,173,600	288,000	6,866,400
Total	$330,030	$863,730	$1,176,300	$791,290	$1,362,970	$923,600	$1,179,430	$290,530	$6,917,880
Automatic System									
Initial investment	48,180	91,980	131,400	86,140	156,220	58,400	77,380	33,580	683,280
Annual operating									
Station	5,280	10,080	14,400	9,440	17,120	6,400	8,480	3,680	74,880
Communication	326,400	856,800	1,166,400	784,800	1,351,200	919,200	1,173,600	288,000	6,866,400
Total	$331,680	$866,880	$1,180,800	$794,240	$1,368,320	$925,600	$1,182,080	$291,680	$6,941,280

Source: Stanford Research Institute

V. FIXED RADIOLOGICAL MONITORING IN SUPPORT OF OPERATIONAL COMMAND

Operational Command must have radiological information throughout its area of jurisdiction to support planning and operations for recovery. To fulfill part of its requirements, Operational Command should have access to information from a fixed monitoring system and from shelters.

The functions and responsibilities of Operational Commands impose considerably more stringent requirements for information on radiological monitoring systems than is derived from the functions of higher level commands. The difference might be viewed as a matter of scaling, wherein the resolution of radiation and all other information as well, is commensurate with the area under the jurisdiction of the command. Operational Commands must deal in more specific terms of field gradients and configurations rather than in the far broader terms of gross areas of the nation. Operational Command, for example, should have the capability of vectoring operational forces and the general population along specific routes at specific times for shelter evacuation or resupply, rescue, and related actions. Radiological information must be of sufficient refinement so that the command can prepare accurate status-of-forces information for transmission to higher echelons. Despite the basic requirement for higher accuracy and resolution of the information, radiological monitoring systems for the support of Operational Command can be developed within the same general constraints and design parameters as utilized in systems to support the higher echelons of command.

A fixed monitoring system for Operational Command, as well as for higher echelons, is required for early situation assessment of the radiological hazards and initiation of operational planning. Action by civil defense units and the general population, except under extraordinary circumstances, must await cessation of the fallout. However, during this interim period the civil defense command should be able to identify the over-all course of action to pursue when operations become feasible. In this sense, the fixed monitoring system to support Operational Command is similar to that supporting higher commands.

The ability of a fixed system to characterize the radiation environment over an area depends both on the characteristics of the fallout pattern as it fell and on the natural and man-made objects on the ground which perturb and otherwise distort the field. In a city, for example, the radiation intensity in a street is directly related to many factors, such as the width of the street, the height of

buildings along the street, and the surface and grading of the street. Because no two streets in any city are identical with respect to these factors, the range of intensity measures throughout the city will have wide limits. This situation would be expected even if the entire city were to be originally contaminated by a perfectly uniform layer of fallout particles.

The extreme variations in field intensity which can develop over a complex surface thus tend to severely limit the accuracy to which a set of geographically spaced readings can describe the field characteristics throughout the area in terms of intensity or dose contours. As in the case of national monitoring, a fixed monitoring system for Operational Command should be designed for the identification of the existing and potential radiological hazard states on an area basis and for monitoring of specific points and resources which critically affected the early phases of recovery operations. Whenever possible, these two functions should be combined in the same monitoring station.

Shelter Monitoring

The first of the two major resources of interest during the early time period is the population housed in shelters. Under the present and proposed shelter stocking plan, each shelter will be furnished with monitoring equipment to provide data for dose records of the shelter occupants and to survey the shelter once it is occupied. This equipment is supplied because the theoretical prediction and calculation of shelter protection factors have certain inherent limitations, and the shelter occupants must be able to determine which areas of the structure are most hazardous to occupy. Moreover, in certain types of shelters there may be a possibility of improving the protection factor of the shelter. These actions can readily utilize survey equipment. Additionally, the shelter equipment can be utilized for support of groups undertaking sorties from the shelters in the early periods.

The degree to which the shelter instruments can be successfully utilized depends upon both the location pattern of the shelter and its individual structural and locational environment. A fixed monitoring system, as noted earlier, should be able to provide the best possible characterization of the fallout field over an area.To fulfill this requirement most accurately, the monitoring action should take place in an open and uncluttered area covered with a uniformly rough material, such as grass. A concrete or similar surface is not advisable as the fallout particles may drift or be blown away after deposition. Most structures planned to be utilized as shelters do not fulfill this requirement. Typically, they are located in built-up areas facing on streets or similar confined spaces. Radiation readings taken in such situations do not represent free field conditions. For example, the nearer a reading is taken to the shelter entrance, the less representative it is of the free field conditions. The reading

that is taken will, of course, accurately represent the intensity and dose at that point, but will not normally characterize the free field conditions. Therefore, the use of the monitoring instruments assigned to population shelters does not appear suited to use as part of the area monitoring system. Rather, their use should be restricted to the description of the internal shelter condition and measurement of the dosage received by shelter occupants.

The procedure for reporting shelter interior intensities or doses of the occupants can be divided into two parts. The first applies to the fallout period when the intensity is rising to its peak level, while the second pertains to the subsequent decay period when conditions are relatively stable. Reporting procedures during build-up can be developed along the same lines as previously discussed for the national system, in which a report is transmitted to the command headquarters each time the dose rate within the shelter reaches the next higher threshold level.

The shelter interior intensity levels at which reports should be made during the build-up period depends on the expected stay-time in the shelter and the reaction time of the civil defense operational units before bringing relief. The minimum reaction time during intensity build-up is fixed by the period of deposition since little, if any, activity can be carried out until cessation of fallout when the situation has become comparatively stable. Under other conditions reaction times will depend on the radiological hazards in the area and the size and competence of the civil defense organization. Moreover, until the situation has stabilized, estimates of dose or hazard state which will exist within a shelter over time are, of necessity, approximations as neither the ultimate magnitude of the deposition nor the age and corresponding decay curve is known.

In view of these conditions the reporting procedures of interior shelter hazards during build-up should be keyed to a reaction or stay-time which could be expected to be at least in the order of 24 hours. Local variations certainly will exist. However, in general, during the fallout period when command must plan early emergency operations and organize the civil defense units, stay times of less than 24 hours do not appear likely. The characteristic of the intensity variation over time that are required to estimate a future hazard state can be based, as in the case of Administrative Command, either upon the expectation that the intensity will persist at a constant level over a given period or change at an assumed rate of increase or decay. During build-up there is no clear-cut choice. With a view to simplifying reporting procedures to the greatest possible extent, the assumption that the intensity at a given time will persist over the time of interest is indicated, especially for the early portions of the build-up period. Naturally, as time continues the intensity variation will become more clearly defined, and consequently more accurate factors can be used.

During the build-up period, therefore, the minimum number of shelter intensity levels to be reported, as keyed to the predicted hazard state thresholds which will exist at the end of a 24-hour period, are shown in Table XXXVIII.

Table XXXVIII

SHELTER INTERIOR DOSE-RATES TO BE REPORTED TO OPERATIONAL COMMAND

Hazard State	Intensity Reporting Point (r/hr)
Noncritical	2
Critical	8
Extreme	40

For example, during the intensity build-up period when the shelter interior dose rate equals two roentgens per hour, the command post should be notified in effect that at the end of a 24-hour period from the time of report the shelter occupants might pass from the nominal class of injury to the noncritical class. Shelters reporting eight roentgens per hour are estimated to reach the critical state within the same time period. These initial reports will provide Operational Command with information for planning early emergency operations. Shelter occupants who are or soon will be in jeopardy can be clearly identified and differentiated from those who are not. Whether or not relief can be provided to the shelter occupants in time to be effective depends upon the equipment and proficiency of the operational units. It would appear somewhat questionable that assistance could be provided in situations where a shelter interior dose rate was 40-roentgens per hour because the outside dose-rate might be larger by several orders of magnitude. This would be especially true for Class C or better shelters.

As shown in Table XXXVIII, the maximum intensity reported from within a shelter is 40 roentgens per hour on a persistency prediction and a 24-hour stay time. Longer stay times in field intensities of this or higher magnitudes place the shelter occupants in the extreme injury state and for operational purposes they can be considered fatalities. These reporting levels indicate that the maximum capacity of survey instruments for use within shelters need be no greater than approximately 50 roentgens per hour. Intensity measurements higher than this in most areas can be expected to be of no operational value

inasmuch as the organizational reaction time likely will exceed the time to death in fields of this and higher intensities.

This reporting procedure should provide Operational Command with sufficient information to carry out its planning function and at the same time to limit the quantity of communication traffic and information to be handled by the headquarters to manageable levels. If the command headquarters is a large and well organized unit with the capability of handling large quantities of information with ease, additional intensity levels at smaller increments naturally could be specified to be reported. This, of course, would be a question to be answered by each Operational Command and would depend upon the number of shelters reporting to a command post, the availability of communication and processing equipment, and similar considerations. In any case, however, all reporting procedures should be designed so that the intensity levels or doses applicable to the hazard state limits are included.

Reports of interior shelter intensities and doses after cessation of fallout and into the decay period should be considered within the broader context of over-all management of the shelter system. Generally, within the normal routine reporting procedures, the dose accumulated by the shelter population should be noted along with other status information, such as the remaining food and water supply and the number of sick and dead occupants. This dose report can be stated either in terms of actual dose or the present and estimated future hazard state of the occupants. This report is made either upon interrogation by the command post or in a preplanned sequential procedure.

Monitoring instruments of 50 roentgens per hour maximum scale, it should be noted, will have ready application to monitoring operations in the later recovery phases. Land mobile monitoring, for example, will be undertaken in fields less than 50 roentgens. Decontamination procedures will require survey equipment which provides accurate field descriptions in the range of 10-100 mr/hr. Rather than purchase, store, and maintain a full inventory of monitoring equipment for each monitoring operation, every effort must be exerted to utilize all survey instruments throughout the emergency and recovery period. While a monitoring instrument can be designed with multiple scales for reading a wide range of intensities, the complexity of the device and the problems attendant thereto generally increase concomitantly. The instrument with maximum scale reading of the order of 50 roentgens per hour, therefore, appears to be a unit suitable for wide and continuous application far into the reconstruction phase of the recovery operation.

The requirements for shelter monitoring equipment thus are apparent from these considerations. First, each shelter should have a minimum of two gamma dose-rate meters. These instruments are required to locate areas which are particularly hazardous or safe and to guide efforts for possible improvement

of the shelter protection factor. They also provide indications of the hazard-state threshold intensities reported to Operational Command. Two gamma dose-rate meters are preferred since teams undertaking sorties from the shelter will require one instrument while one should always be available to the shelter group. The accuracy of these survey instruments, as discussed in Section III can be in the order of ±20-25 percent with a maximum range of 50 roentgens per hour.

Second, each shelter should have at least two self-reading dosimeters for monitoring the dose received by the shelter groups. The capacity of the instruments should extend to at least the critical injury class dose limit--200 roentgens. Dose, of course, can be determined from survey instrument measurements, but the advantages of a direct reading dosimeter for dose measurements are obvious. As in the case of the dose-rate instruments, two are preferable so that one may be utilized by teams undertaking sorties from the shelter. Moreover, in some shelters where appreciable nonuniformity of dose rate has been observed from point-to-point, more than one dosimeter may be required to adequately monitor the doses accumulated by the shelter occupants. In view of the uncertainties of relating dose to biological effects indicated in Section III accuracies of ±35 percent are adequate.

Finally, low-range beta dose-rate meters with a maximum reading of about 50 mr/hour are desirable for the Class A and B shelters. Though the beta hazards are of secondary importance monitoring of the shelter occupants as they enter and the crews returning from sorties appears desirable. Because of the extreme difficulty in making beta-ray measurements in a gamma-ray field, the use of these instruments would be restricted to the Class A and B shelters for most fallout conditions.

Area Monitoring Station Locations

The second category of resources of interest are those facilities on which the early recovery and survival of both the local area and the nation critically depend. Typical critical resources required to support the nation have been identified previously. Localities where these resources are situated should take cognizance of them in developing any monitoring system design and operational procedures so that the Operational Command can properly reply as to the detailed status of the resource at the request of Administrative Command.

The specification of resources which are critical to Operational Command during the early recovery period are more difficult to determine. Because of the wide variation in local areas throughout the nation, the local authorities are in the final analysis best, if not solely, qualified to identify these facilities. The critical resources can be expected to become more or less self evident in

the process of preparation of local survival and recovery plans. These points typically may include the following installations.

1. Major points in municipal water systems. Decontamination, fire fighting, and other survival actions require water in large quantities. The radiological situation at major pumping and distribution points in a system may be critical in determining if the stations can be manned for control of water flow, diversion, and damage control. Lack of access to these points could influence the course of recovery.

2. Electrical generating and distribution system facilities. Recovery operations can be highly dependent on the supply of electric energy. Any water system, for example, which contains pumping units would probably require electricity for operation. Thus, the radiological hazards at major generating stations and important switching yards should be known in the early emergency phases.

3. Hospitals and mass care facilities.

4. Designated assembly areas for civil defense operational units. Recovery operations should be initiated as soon as possible after the cessation of fallout. Certain operational units, such as municipal fire and police organizations and others which are regularly established full-time units, perhaps can begin operations directly from their shelter locations within general guide lines established by command. The part-time and volunteer groups, however, will likely require some degree of organization, assignment of duties, and perhaps elemental training before operations can begin. To facilitate this procedure, assembly areas for these personnel should be identified in the local survival and recovery plan. These areas logically should be monitored. Thus, during the time of intensity build-up when the Operational Command has established its emergency recovery procedures, the status of these assembly areas can be determined and proper guidance transmitted to the personnel in shelters concerning to which area they should report and when.

5. Major points in communication and transportation systems. The need for radiological information concerning these points depends upon their importance in early operations. If, for example, an area has a highly efficient shelter system with appreciable protection factors for most structures, the need for transportation to carry out evacuation or resupply of the population may be minimal. Thus, early radiological information at transportation points may not be required. These can be monitored at later times by mobile teams.

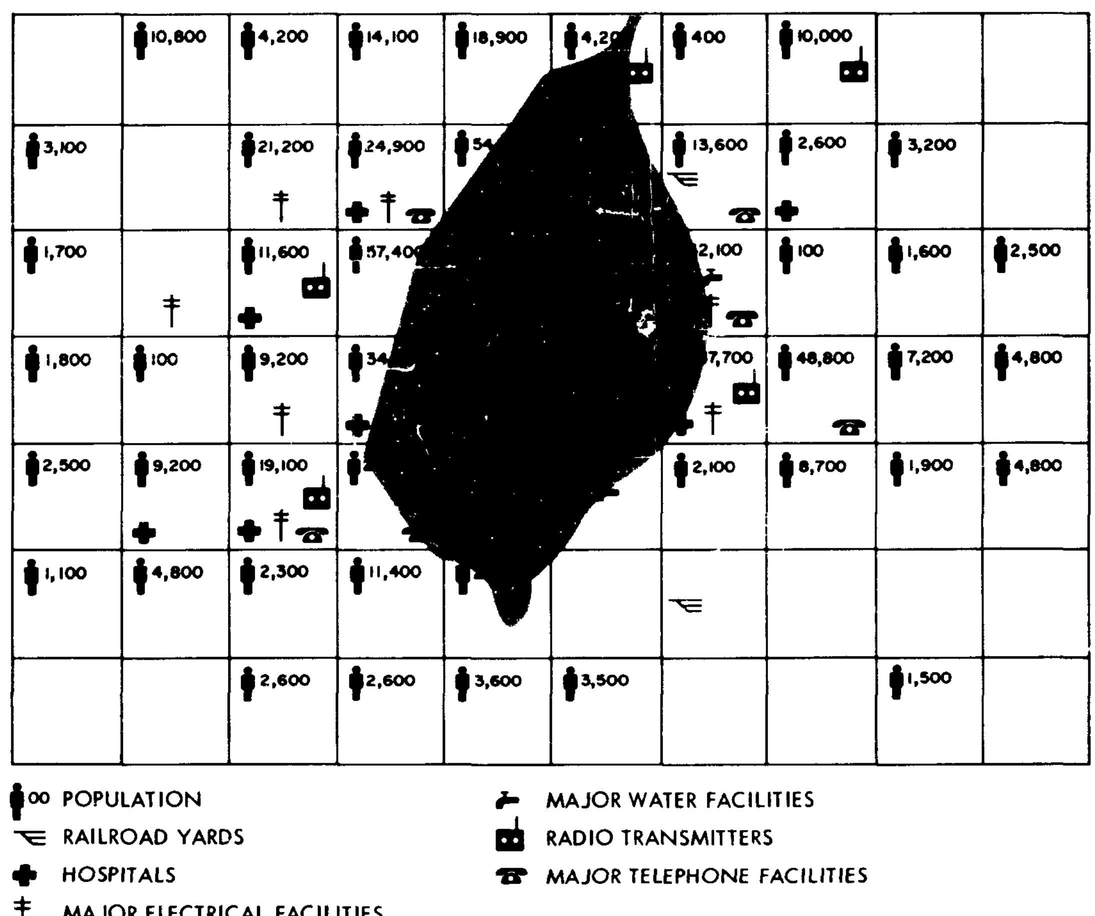
6. Specialized or unique resources. This category could include medical and drug storage facilities, large food processing and storage plants, and similar installations which affect the local, as well as perhaps the early national recovery. These resources might be ranked in the next priority after those for which information is required by the highest echelons immediately following the first attack and be covered by the fixed monitoring system to support Administrative Command.

As noted earlier, whenever possible a fixed monitoring system should be designed to monitor both these critical resources and shelters and at the same time be able to characterize the fallout situation throughout the entire area. The locational pattern of a national system to provide these data is suggested to be derived from (1) the joint consideration of the expected number of stations which detect the various hazard states and (2) the common base on which the resources of interest should be aggregated or summarized to provide suitably accurate assessment information. A similar approach appears suitable for local areas, i.e., spacings should be sufficiently small so that the areas of different hazard states can be identified.

Generally, the area over which Operational Command has jurisdiction may be small with respect to the area of the hazard state so that an entire city or county, for example, could be in the same hazard situation. Normally, Operational Command could be expected to have the capability to use, and the need for, information of greater resolution. More detailed definition of the radiological situation enables command to more efficiently vector the earliest deployed forces, organize mobile monitoring activities, and otherwise more quickly initiate operations.

The spacing of fixed monitoring points also depends upon the characteristics of the area, such as its size, the population location, and the distribution of the critical resources of the type previously noted. These will have wide variations in pattern characteristics from city to city. A typical aggregation of these facilities on a 4-kilometer (2.5 mile) grid is shown in Figure 29 for St. Louis, Missouri. The day-time population is indicated along with a number of vital facilities, including hospitals, major electrical and water system stations, and primary communication points. As in the national situation the resources of interest tend to be located in the same area so that a monitoring system for one item essentially provides coverage for others as well. Generally, as the distance from the central city increases the concentration of all resources tends to diminish rapidly, except for the water and electrical installations, which typically encircle the city. Thus, in this situation, the spacing of monitoring stations on a 4-kilometer grid to cover the area of significant resource concentration would be in the order of 30 stations. The remaining 40 grid-squares shown in Figure 29 have resources of relative insignificance.

Figure 29
SAMPLE AGGREGATION OF CRITICAL RESOURCES IN ST. LOUIS, MISSOURI, ON A 4-KM (2.5 mile) GRID



Sites for these stations should be chosen carefully and, insofar as possible, should be identical in their radiological characteristics. The monitoring point should be located at the center of an area whose surface has a uniform roughness. Grass or gravel are typical desirable surfaces. The detector point should be at least 100 feet, and farther whenever possible, from any prominent object, such as buildings or stands of trees. Even greater distances are preferable for stations in areas of high-rise buildings. The local area may not always be able to satisfy these criteria for every monitoring station, and reasonable compromises may be required in either the site specifications or the desired spacing between stations. These conditions can only be determined by local surveys. Within most cities, however, a reasonably wide variety of sites suitable for monitoring stations normally should be expected to exist. These include the following:

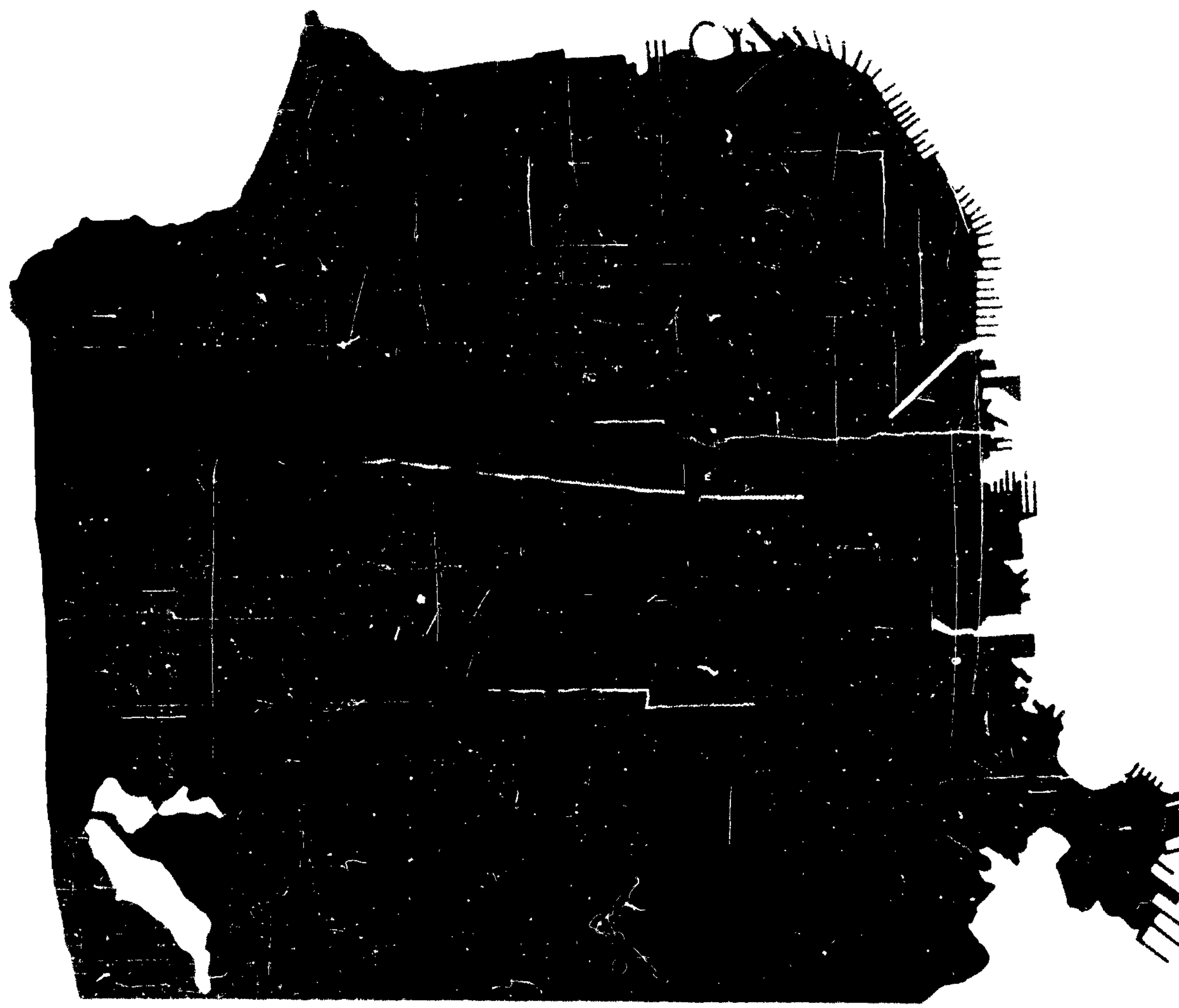
Airport areas beyond runways
Cemeteries
College and university campuses
Golf courses
Parks, squares, and recreational areas
Riverbanks and beaches
Military reservations

Figure 30 illustrates the locational pattern of the park and recreation areas of San Francisco as an example of the possible feasible sites for monitoring stations in a city. Clearly, the points are distributed more or less uniformly throughout the city, with a total of over 75 locations. The size of the park areas tends to increase as the distance from the central business area increases, but this is of no importance as long as the smaller parks are large enough to meet the station siting criteria.

Area Monitoring Station Reports

The reporting procedures for these stations can be similar to those employed in the national system. That is, intensity reports on an estimated stay time and intensity persistence prediction are made as the hazard-state threshold is reached. However, a major difference between this and a national system should be noted--the national system is primarily for determining the status of the nation and of damage assessment in the early time period. In a local area the system serves not only this broad function, but more importantly it is used to assist in determining when emergency recovery operations can be initiated. Radiation fatality information in a local situation can be obtained directly from shelters. Estimates based upon free-field intensity measurements would not be expected to be necessary for this purpose, except for estimating the casualty rate for the portion of the population unable to reach authorized shelters.

Figure 30
REPRESENTATIVE DISTRIBUTION OF SITES SUITABLE FOR FIXED MONITORING STATIONS IN SAN FRANCISCO, CALIFORNIA



SOURCE: *Parks and Recreational Areas in San Francisco*,
San Francisco Department of City Planning, April 1954.

Because of this difference the reporting procedure of the system and the station spacing could be varied to some extent to satisfy the local conditions. Moreover, because the communication links are comparatively short, some possibility should exist for the use of the analog form of transmission rather than being restricted to a digital format.

Because the information from these monitoring points is used to plan and support recovery operations, the maximum free-field intensity reading and the intensity increments which the stations can report should be keyed to the operational units' capability to act in a contaminated area. Except in the most extreme circumstances, operational units would probably not carry out recovery actions in radiation fields, which produced a lethal dose in times of the order of one or two hours. Consequently, the maximum intensity which a fixed monitoring station can report typically need not exceed 1,000 roentgens per hour.

The lower levels of intensity which should be reported by these stations depend upon the monitoring capability of the operational units and the ability of command to exercise control over the units. Generally, Operational Command is expected to assign operational units to specific missions, vector the units to the scene of operations, and prescribe the dose limits to the unit personnel. The time to complete the mission, of course, should be less than the time to accumulate the maximum dose prescribed. The first sorties of many units possibly may be undertaken on the basis of fixed station readings only. For these early operations, therefore, the need for monitoring equipment by the operational units is clear. Within the guidelines established by command, the operational units must have the monitoring capability to determine in detail their radiological condition and act accordingly. As these sorties continue and mobile monitoring reports are accumulated, the need for information from the fixed monitoring system decreases and is finally eliminated altogether.

The intensity levels at which the monitoring stations report should be established in such a manner that the dose expected to be received by the operational units can be estimated. Because these operations and the dose estimates applicable to them take place after the cessation of fallout, the estimates preferably should take into consideration the decay of the field rather than use the assumption that the field will persist over the time of interest--as was done in the build-up period for casualty estimates and initial planning.

If the system operates with digital data, the intensity levels which each station can report must be specified in advance, as indicated for Administrative Command, in order to design the monitoring and encoding equipment. Accurate measurement of the decay properties requires relatively small increments between intensity reports, therefore implying somewhat complex coding and conversion equipment. Because of these constraints and the fact that typical Operational Commands are expected to have relatively few monitoring stations

within short distances of the command post, an analog data reporting system should be entirely suitable if the system is automatic. Moreover, it is quite likely that most Operational Command headquarters will use entirely manual procedures so that the reporting of intensity measurements in analog form directly in terms of dose rate should be preferable to using a digital code.

Most local monitoring systems will likely utilize telephone links between the command headquarters and the monitoring station. To take advantage of the lowest possible tariff, to permit freedom in connection of the monitoring points to virtually any telephone link, and to permit maximum flexibility in routing, the form of the analog signal should be elementary. Since the bulk of the telephone plant is designed to handle voice traffic, the monitoring station signal should have the same characteristics insofar as possible.

A number of equipment designs to fulfill these requirements could be developed. A typical system with these characteristics would consist simply of installing at the monitoring point a variable frequency audio oscillator whose frequency was controlled by the survey instrument. For example, an intensity of 1,000 roentgens per hour could correspond to 2,000 cycles per second and 500 roentgens per hour to 1,000 cycles per second. Most common telephone circuits will readily accept a signal from 100-200 cycles per second to as high as 3,000 cycles per second. If the oscillator were adjusted in increments of 100 cycles per second, a total of 290 intensity readings between zero and 1,000 roentgens per hour could be achieved. This resolution would be in far greater detail than required for planning purposes but would be altogether suitable in determining field decay rates. Command post facilities to determine the transmitted frequency in increments of 100 cycles per second would be elementary. A system of this type could operate on an interrogate-respond principle with the command center perhaps dialing the monitoring station through the conventional telephone exchange each time a reading was desired. The monitoring station links would, of course, require preferential treatment, and be retained in line-load control of the telephone system. Otherwise engineered private circuits would be required. Obviously, none of these problems arise in a manual system--except in the communication portion.

System Cost

The cost of fixed monitoring systems to support Operational Command will vary widely, depending on size and complexity, from city to city throughout the nation. At a station spacing in the range of two to three miles, most cities and local areas could be covered adequately with between 10 to 30 stations. For example, at a 2.5-mile spacing, 25 stations would monitor an area of about 150 square miles which is larger than many cities.

The station unit costs reported in Tables XXIX and XXX should generally apply to these installations. As noted earlier, however, if the manned stations can be established within existing shelters, the unit costs will be significantly reduced. The cost of the shelter itself, as well as the costs of equipment and furnishing and perhaps power and communication, can be significantly reduced. Under these conditions the unit cost of a manned station should be as shown in Table XXXIX.

Table XXXIX

UNIT COST OF A FIXED MANUAL MONITORING POINT OPERATED FROM A CLASS A SHELTER

Initial Investment	1,000 r/hr Maximum	10,000 r/hr Maximum
Monitoring Equipment	$200	$500
Electric Power Facilities	50	50
Training	160	160
Total	$410	$710
Annual Operating Cost		
Instrument Maintenance @ 5% of Initial Cost	$ 10	$ 25
Telephone @ $5/month	60	60
Inspection, 12 times per year	24	24
Total	$ 94	$ 109
Total Rounded	$ 90	$ 110

The system costs for an automatic system and a manual system operating in support of Operational Command from Class A shelters are summarized in Table XL.

Table XL

COSTS OF A 10-STATION FIXED MONITORING SYSTEM
TO SUPPORT OPERATIONAL COMMAND

System	Initial Investment	Annual Operation
Manual, specially designed station	$33,000	$1,100
Manual, within a Class A shelter	$ 4,100	$ 900
Automatic	$14,600	$1,600

VI AERIAL MONITORING SYSTEMS IN SUPPORT OF COMMAND

Aerial monitoring operations can be established in support of command after the fallout period. Aerial monitoring is not radiation limited, it is the most mobile monitoring system, and it is ideally suited to tactical support of command. This section explores the significant operational parameters of aerial monitoring.

Aerial monitoring systems form an integral part of the total monitoring capability required to provide radiological information to support the functions of civil defense command. Because of the speed and mobility of aircraft, their deployment appears to be well suited to a form of tactical and flexible support of both Administrative and Operational Command. Moreover, since aerial monitoring procedures are not limited to a maximum measurable radiation intensity level, they could be used in conjunction with land mobile systems which are limited by the dose to the monitoring crews. In the very early period of the attack and shelter phase, the primary sources of radiological information include the fixed monitoring systems and reports from shelters. After the cessation of fallout, however, aerial monitoring operations--and mobile procedures as well--may be initiated.

This type of monitoring could not be employed until after cessation of fallout for two reasons. First, a radiation instrument carried by an aircraft measures the total field between the aircraft and the ground. The two components--that in the air and that on the ground--cannot be accurately differentiated with only one reading; the intensity background created by the airborne particles is too large to permit accurate ground readings. The second reason, which essentially involves background considerations as well, is that the aircraft in flying through a contaminated air space will build up deposits of fallout material on its exterior surfaces. While this may pose a threat to the aircraft crew, the primary result is that the monitoring equipment carried will detect these irradiations and thereby obscure the ground measurements. It should be noted in passing that the survey aircraft must be protected from fallout at their bases or be decontaminated prior to starting the survey operation. Moreover, the landing strips used by survey aircraft must be free of contaminants at the time of take-off. Otherwise, particles on the runway may be picked up by the wheels and other parts and may create a sufficiently high background to thwart operations.

Instrument or vehicle contamination must be recognized as a problem in any type of radiological monitoring system. In the case of aerial monitoring, however, it is of especial significance because of the large attenuation which the fallout field undergoes between the ground and the monitoring aircraft. For example, background contamination of 0.5 r/hr on an instrument on the ground which is measuring a field of 100 r/hr is of little significance in comparison with the same situation in an aircraft at 2,000 feet where the ground field has been attenuated by a factor of about 200. In the latter case the background intensity is the same as the field intensity.

Aerial monitoring systems are best suited to the survey of relatively open, homogeneous surfaces which are flat or have gentle undulations. Central cities, built-up areas, and other complex man-made or natural areas tend not to be suited to aerial monitoring because of the virtually infinite number of geometrical variations which affect the radiation field. In addition, pilot skill, as well as the response time of the aircraft, limit the ability to follow terrain or to maintain a constant altitude over it. This limitation generally increases with the speed and size of the aircraft. However, corrections for terrain variations could be applied to all intensity measurements either as they are recorded or at a later time.

Flight Procedures for General Area Monitoring

Aerial monitoring techniques improve with increasing field intensities as the possible radiation background represents a smaller percentage of the total intensity detected. This combined with the fact that aerial monitoring systems are not radiation-limited tends to indicate that the system should be employed for survey in high intensity areas. However, because of the time delay in initiating aerial survey procedures, these areas will have decreased in size and therefore may be difficult to locate by aerial methods alone. The ground monitoring systems may be required to provide the initial guidance and direction to aerial survey forces as to the approximate locations and areas in which to initiate operations. Otherwise, as the time after fallout increases, the courses flown by the monitoring aircraft must be continually decreased in spacing so that areas of high radiation hazards can be detected.

This condition can be illustrated by considering the continual shrinkage in area and dimensions of standardized H+1 fallout patterns over time. Table XLI shows the major downwind dimensions of standardized contours for selected weapons under 30-mile-per-hour winds as a function of time after weapon detonation. The standard exponential decay is used here, and, as can be noted, the intensities of greatest hazard rapidly vanish over time. For example, with the 5 MT weapon the 1,000 roentgen per hour contour essentially disappears at H+7 and the 100 roentgen contour has vanished by H+35.

Table XLI

DOWNWIND DISTANCE OF STANDARD INTENSITY CONTOURS
AS A FUNCTION OF TIME[a]
(MILES)

Yield	Intensity (r/hr)	H+1	Distance at Times of: H+7	H+14	H+21	H+35	H+49
1 MT	1	450	320	300	270	240	200
	10	320	200	170	150	100	70
	100	200	70	50	--	--	--
	1,000	70	--	--	--	--	--
2 MT	1	560	420	410	350	315	270
	10	420	270	230	200	160	110
	100	270	110	90	80	--	--
	1,000	110	--	--	--	--	--
5 MT	1	760	560	510	430	430	370
	10	560	370	330	300	250	180
	100	370	180	150	100	--	--
	1,000	180	--	--	--	--	--
10 MT	1	960	730	670	610	560	500
	10	730	500	440	390	340	270
	100	500	270	170	120	--	--
	1,000	270	--	--	--	--	--
20 MT	1	1,200	920	850	790	720	640
	10	920	640	580	510	450	370
	100	640	370	200	150	100	--
	1,000	370	--	--	--	--	--
50 MT	1	1,620	1,270	1,160	1,140	1,000	910
	10	1,270	910	820	740	650	550
	100	910	550	460	300	250	200
	1,000	550	200	--	--	--	--

a. 30 mph winds.
Source: Stanford Research Institute.

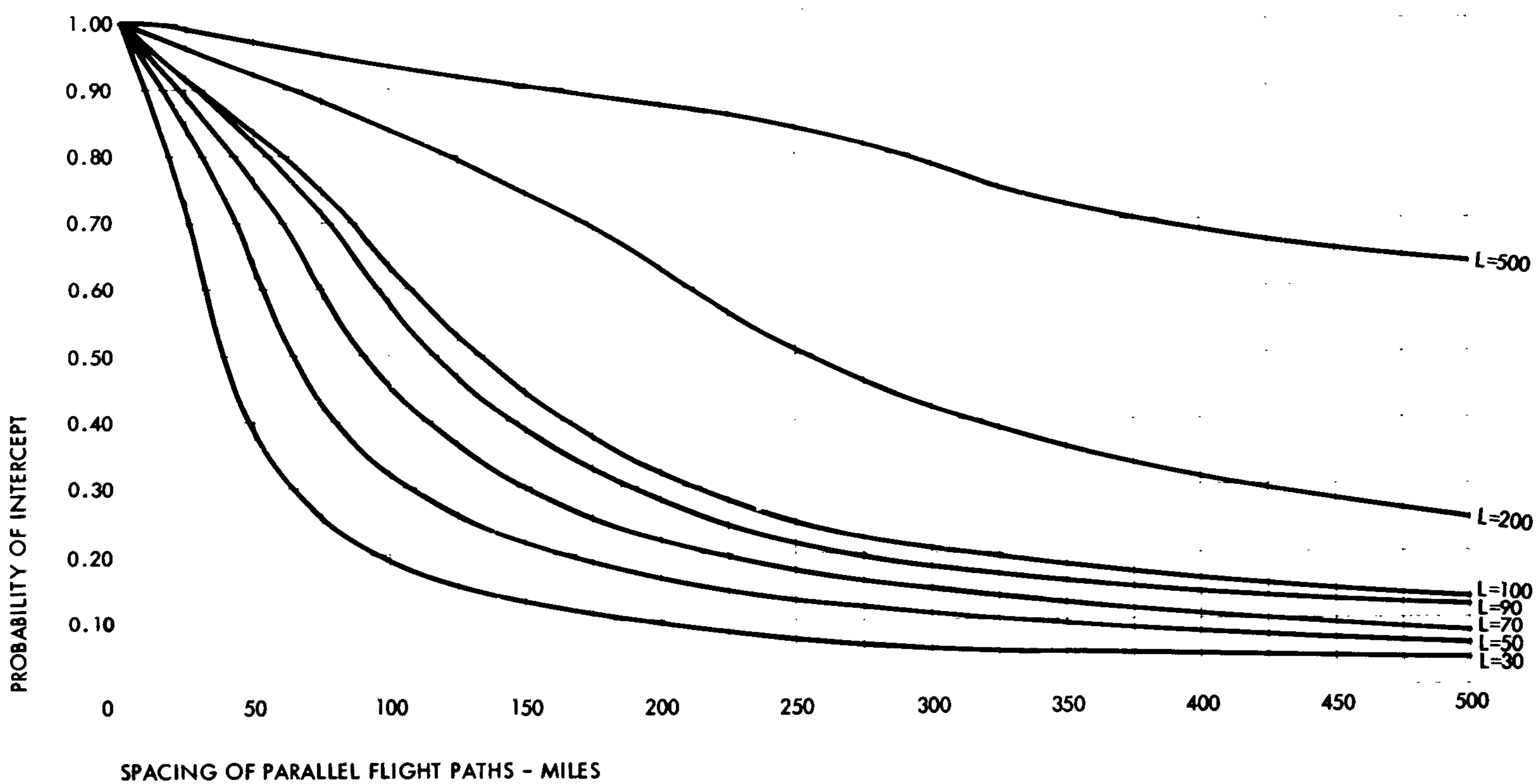
These dimensions are the standardized downwind distances associated with a constant wind. It is well known from experimental weapon tests that substantial variation will occur in these dimensions, as well as in the overall configuration of the pattern. In the idealized patterns one closed contour defines one intensity level and each unique contour encloses all higher valued contours. In actual fact, however, a fallout pattern may contain several so-called hot or cold spots within the pattern and thereby vary substantially from the idealized patterns. Such a typical condition was illustrated in Figure 5. These characteristics inject uncertainties into preplanning of the routes which aircraft should traverse in conducting monitoring operations. The ground zeros either will be known or observable from the air and will provide clues for the configuration of flight paths for field measurements in the vicinity of the ground zeros. However, for areas not immediately associated with the points of detonation, the problem of orientation is more acute.

In general, the monitoring flight path spacing must be commensurate with the dimensions of the features of the field that are of interest. The dimensions shown in Table XLI would likely be the maximum distances of the pattern since wind variability would tend to bend and otherwise distort the pattern. Under the condition [illegible] t the areas of interest of the fallout field will be randomly positioned, the spacing of the flight path required to detect these areas is shown in Figure 31. The probability of detecting field conditions with its major dimension, L, between 30 and 500 miles is indicated for parallel flight spacings up to 500 miles. For example, to detect a field condition whose major dimension is 50 miles, a flight spacing of 70 miles provides a probability of detection of 0.45, and a spacing of 100 miles, a detection probability of 0.32. These relationships can be compared to the major dimensions in a fallout pattern over time to determine the flight spacing required to detect the various areas of contamination in a fallout pattern. Specification of an adequate spacing depends upon the time delay before aerial operations could be started. The longer the delay, the smaller would be the required spacing, if high intensity areas were to be accurately identified.

These flight spacings and the probability of detecting high intensity areas generally apply to an aerial monitoring system which would operate without benefit of other radiation information. However, at the time an aerial system could be deployed, some radiation information should have been assembled and processed from both the fixed monitoring systems and the status reports from lower echelons. Thus, except in the total absence of such intelligence, the monitoring aircraft can be provided with flight information and can be vectored into the areas in which aerial monitoring is required.

Ground monitoring systems, in addition to demarking areas of interest for aerial systems, appear to be required for purposes of calibration and

Figure 31
PROBABILITY OF DETECTING RANDOMLY DISTRIBUTED AREAS WITHIN FALLOUT PATTERNS AS A FUNCTION OF SPACING BETWEEN PARALLEL FLIGHT PATHS L=MAJOR DIMENSION OF THE AREA OF INTEREST



checking of aerial systems. That is, because of the danger of contamination of the aircraft and the consequent increase in the background of aerial measurements, the aircraft should fly periodically over a ground station and compare its readings with those on the ground. This comparison must be carried out in real time, so that if the aircraft has become contaminated either the proper correction factors can be applied or the flight can be terminated. This calibration procedure requires an air-ground communication link between the aircraft and either the ground station itself or a nearby communication facility linked to the ground station.

The time which would be required to complete an aerial survey of the nation depends upon the course spacing, the speed and number of aircraft, and the size of the area covered by each aircraft. Moreover, because of the necessary delay before such monitoring activities can be started, radiation information acquired from other systems during the delay period should be utilized in determining the survey procedures required to carry forward the most efficient operation. In the absence of any prior information, however, when Administrative Command must acquire the definition of the radiological situation from aerial systems alone, the survey procedures could become lengthy.

Table XLII illustrates the total flight path required to cover the nation on a rectangular grid with selected spacings and the total flight time required by the operation conducted under various aircraft speeds. The actual time required to complete a nationwide survey would of course be dependent upon the number of aircraft used. The table shows the maximum time burden on an aerial monitoring system for survey of the entire nation.* The flight time required to complete survey procedures at spacings commensurate with the expected ground conditions, as indicated in Table XLI, could typically extend to 400 hours or more. Time intervals of this order of magnitude tend to depreciate the value of the information acquired, because during the interval status-of-forces information as well as more accurate radiation information can be acquired by Administrative Command through other systems.

---

* Certain areas, such as the Rocky Mountains, might be excluded from consideration since the population and the resources of interest are widely scattered and can therefore be more efficiently monitored by other systems. Moreover, mountainous regions often are not well suited to aeri^l monitoring.

Table XLII

FLIGHT TIMES FOR AERIAL MONITORING OF THE UNITED STATES WITH SELECTED FLIGHT-PATH SPACINGS AND AIRCRAFT SPEEDS

Flight Spacing (miles)	Total Flight Distance (miles)	Flight Times in Hours at Aircraft Speeds of: 600 mph	400 mph	200 mph	100 mph
10	300,000	500	750	1,500	3,000
20	150,000	250	375	750	1,500
30	99,600	166	249	498	996
40	75,600	126	189	378	756
50	60,000	100	125	300	600
60	52,000	87	130	260	520
70	43,200	72	108	216	432
80	37,200	62	93	186	372
90	33,600	56	82	168	336
100	30,000	50	75	150	300

System Configuration and Operational Constraints

Aerial monitoring systems can have a wide range of operational configurations. Basically, they can be divided into two parts: (1) the small light aircraft operating over relatively short ranges from its base over terrain familiar to the monitoring crew, and (2) the long-range, relatively high performance aircraft; with operational ranges of hundreds of miles, operating over terrain both familiar and foreign to the monitoring crew. Both systems must possess the same general capabilities, but these can be satisfied in considerably different ways. The major capabilities which the survey aircraft must have, in addition to the monitoring equipment, include equipment to measure height above the ground, position fixing and navigational facilities, and possibly an IFF capability at least for the high performance aircraft. In general, the operation of these units, excluding calibration of the monitoring instruments, should be independent of any ground support. For example, to rely on a ground-based navigational system to be continually operating after the war starts appears to be of doubtful wisdom.

Survey Altitude

Perhaps the greatest constraint to the accuracy of aerial monitoring systems is that of determining the height of the aircraft above the ground. The

relationship between height and attenuation has been established. The increase in attenuation with altitude is a rapidly rising function with, for example, a factor of 28 at 1,000 feet and an attenuation of 190 at 2,000 feet. This relationship indicates clearly that the altitude of the aircraft must be held within close limits of its assigned elevation to acquire reasonably accurate readings. Otherwise, each reading will require correction as a function of altitude variation. The range of error in the attenuation factor which could occur because of errors in altitude is summarized in Figure 32 in normalized form. The errors are essentially constant for any altitude maintained within specified limits. At both 1,000 and 2,000 feet, the error is in the order of 40 percent for an elevation error of ±100 feet. As the altitude error increases, however, there is a slight reduction in the error of the attenuation with increasing altitudes, but this variation is small with respect to the errors themselves and does not appear to be operationally significant.

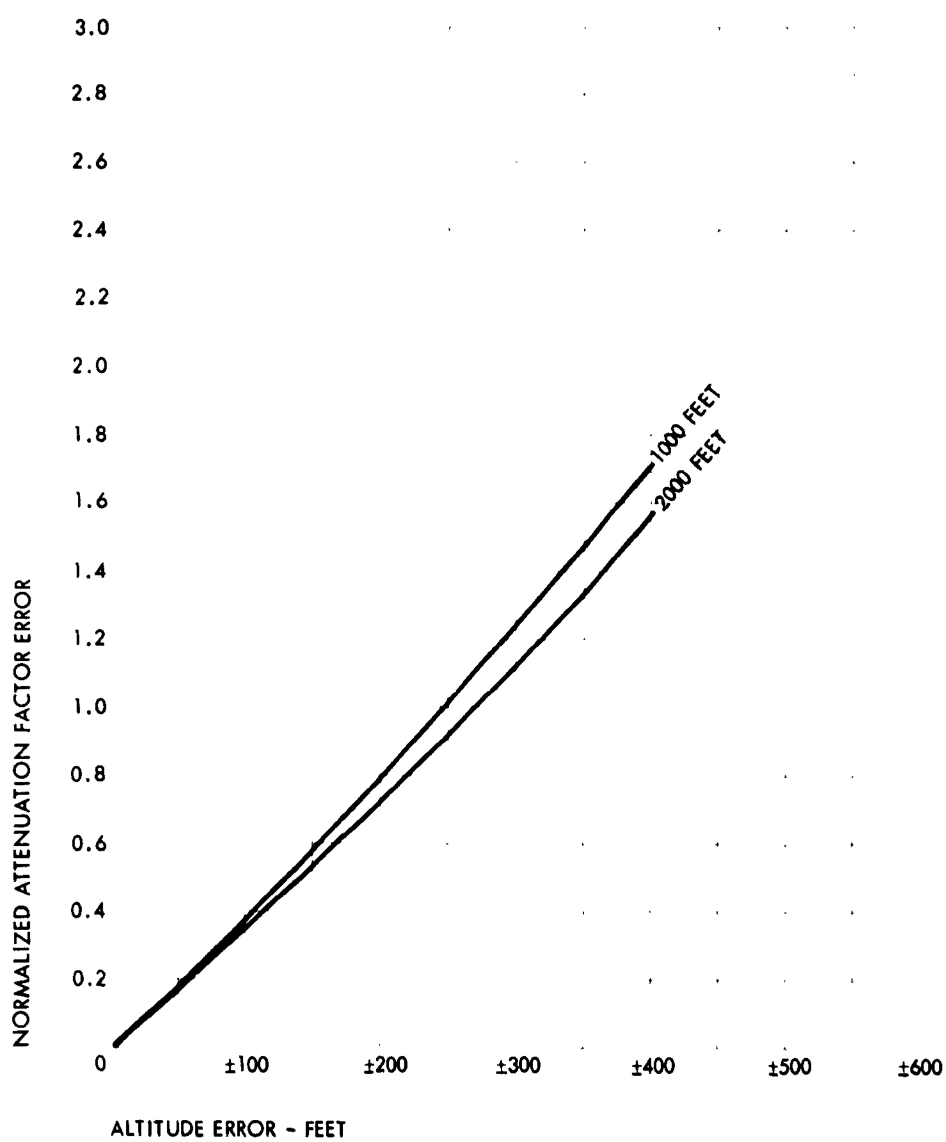
From these data it is quite apparent that accurate altitude information is a major requirement for aerial systems. Numerous techniques to acquire altitude information are available. Probably the most common are the barometric altimeter and the radio height finder. In a postattack situation the use of the barometric device may be limited to aircraft flying short distances from their bases for short periods of time. That is, because the atmospheric pressure varies constantly, the barometric altimeter must be calibrated continually.

In peacetime these pressure-altitude correction factors are provided to aircraft on a continuous basis. It is difficult to determine if such service would be continued during and immediately after an attack, but it appears questionable to base a monitoring system design upon the assumption that the corrections would be at least universally available. In the absence of barometric corrections, a survey aircraft is limited to calibration of his altimeter at the base prior to his departure and continuing the flight until he judges that his altimeter has lost calibration. This permissible flight time depends upon the weather conditions in the area at the time of survey. In the absence of weather fronts, strong winds, and similar weather conditions, the altimeter can be expected to retain calibration for a matter of hours. When these conditions are present, calibration accuracy is extremely tenuous.

Radio altimeters and similar electronic equipment are of course not limited by this restriction. Aircraft so equipped are therefore not limited by the absence of proper barometric corrections and can operate with greater freedom in time and range.

It should be noted that the commonly used height-attenuation relationship appears to be based upon sea-level conditions. The attenuation factors are derived (and partially checked with limited experimental data) with respect to the variation in air density and consequent absorption characteristics with

Figure 32
NORMALIZED ERROR IN ATTENUATION FACTOR FOR AERIAL SURVEY VERSUS ALTITUDE ERROR



increasing altitude above sea level. Large and significant areas of the nation, however, are situated at elevations substantially above sea level. For example, the bulk of the region westward from eastern Pennsylvania through Ohio, Illinois, and adjoining regions lies within the general range of 600 to 800 feet above sea level. Southwest Texas, New Mexico, and Arizona have large areas at 1 000 feet and above. The use of this standard attenuation relationship for survey of land at elevations other than sea level thus should be recognized as a departure from the standard and as a source of survey error.

Position Location

Numerous techniques and equipment to determine the positions of the survey aircraft during the monitoring operation are readily available. As noted previously, the procedures used should be self-contained within the monitoring aircraft and not dependent upon ground support. Moreover, many of the ground-based electronic systems do not provide reliable and complete coverage for altitudes typically associated with aerial monitoring The most elementary position-fixing system is of course pilot observation of ground features. Radiation readings are made in relation to such features as highway intersections, bridges, and streams. The most effective survey in this case would be undertaken by a flight crew completely familiar with the area. Flight crews unfamiliar with the area can utilize maps and charts for location information, but this procedure would tend to increase the possibility of error in position determination as well as increase the time of survey. Because of these conditions aerial survey by visual flight rules tends to be restricted to limited areas around the landing field at which the survey aircraft are based

Position-fixing by instruments, such as doppler navigation facilities, provides the aircraft with the capability of maintaining its position with respect to its base or other designated points regardless of the degree of familiarity of the pilot with ground terrain and surface features. Position accuracy is a matter of equipment design and calibration intervals.

Visual flight rules and positioning procedures produce a set of intensity readings keyed to geographical features of the area. Position information of this type is of great meaning to the civil defense personnel, such as the Operational Command headquarters staff, who are familiar with the area. However, for higher echelons unfamiliar with the characteristics of the locale, such position information may be difficult to use, and probably would require transformation into a standard coordinate system before transmission to superior organizational levels. On the other hand, position information originally established on a coordinate system basis can be more readily transmitted and comprehended by higher command echelons, but it appears doubtful that such positional information will be of convenient and readily usable form for local command and especially operational units.

Communication

Because aerial monitoring systems cannot be deployed until at least the time at which fallout stops, generally their use in early emergency recovery planning is restricted. Data to that point will be acquired from the fixed monitoring stations and shelters. At the time aerial monitoring is begun, the radiological situation will have stabilized to some extent, and certain recovery operations will have been initiated. The need for rapid acquisition of information--perhaps at the sacrifice of accuracy--will have decreased appreciably. If perimeter monitoring in support of ground mobile monitoring is being carried out, for example, perhaps voice radio will be advisable for purposes of coordination and spot reporting. However, in operations involving a systematic survey of specified areas, where data are being acquired in a preplanned format, there appears to be little need for continuous transmission of data--raw or reduced--to the command post. The time aloft for survey aircraft generally will be short with respect to the organizational cycle and reaction time, as well as the rate at which the radiological situation is changing. Therefore, analysis and reduction of detailed aerial monitoring information at the command post should be possible after the aircraft has returned to base.

VII LAND MOBILE MONITORING TO SUPPORT OPERATIONAL COMMAND

Land mobile systems are required to support both Operational Command and civil defense units. The land mobile monitoring system provides the greatest accuracy and detail of information of any of the systems considered, although it is radiation limited because of the dosage to the monitoring teams. Current instrument design standards, such as accuracy and range, appear to be suitable.

Subsequent to the termination of the fallout period, when the radiological situation has become comparatively stable, land mobile monitoring procedures can be initiated.

The time at which the monitoring units can be deployed and the areas which they can survey depends primarily upon the intensity of the field in the area. Unlike other monitoring systems land mobile monitoring is limited by the dose which the monitoring crews will accumulate during the operation. The maximum dose which a monitoring crew will be required to sustain must be determined by the Operational Command. The decision must be based primarily upon the need for mobile monitoring information and the number of monitoring crews available to command. If, for example, command has one monitoring team per 10 square miles the decision as to the maximum dose and dose rate to which the team will have to be exposed will differ from a decision made when there are five teams per 10 square miles. Doses, in other words, can be shared among a greater number of teams in the latter situation and the maximum permissible dose established by command likely could be less.

The first monitoring efforts will probably be based on (1) the general hazard situation defined by the fixed monitoring system, and (2) the requirements for detailed radiological information describing the hazards at locations of particular interest, such as major evacuation routes and the critical resources previously indicated. As the areas over which mobile monitoring has been conducted are continually enlarged, the need for information from other systems decreases correspondingly. Clearly, no other monitoring system can provide the same accuracy and detail of information as that acquired by land mobile procedures. In all probability, mobile monitoring systems will be required for extended intervals after the war. During the reconstruction and later phases the function would most likely be included in Public Health or a similar group. In the early emergency and initial recovery period, however, mobile monitoring is inherently an integral part of, and plays a vital role in, the civil defense organization.

Sources of Land Mobile Monitoring Information

Mobile monitoring information to support the early recovery operations should be acquired from the following three organizational units:

1. Operational units engaged in nonradiological countermeasures.

2. Operational units deployed for repair and operation of critical resources.

3. Formally organized mobile monitoring units.

Operational units engaged in nonradiological countermeasures typically would include fire fighting crews, rescue forces, and similar groups. These units, at least in the early time periods, must have radiological equipment organic to the force for their own protection. Each unit should be able to decide on the spot whether or not the accrued or potential dose will place the unit in jeopardy if operations are continued in the area. Moreover, the instruments will enable the units to choose the precise approach to the scene of action from the broader vectoring information provided by Operational Command.

The amount and accuracy of the radiological information which can be acquired from these units may be minimal since their mission is to counter other hazards--and not to monitor radiation fields. The information is likely to be (1) somewhat inaccurate with respect to both location and time because the measurements would not be expected to be made in a systematic manner and (2) unavailable until the units have returned to their bases of operations after completion of their missions. Nevertheless, any monitoring data which these units do collect is of value, and the units should be considered an adjunct to the mobile monitoring system.

The operational units deployed for the repair and operation of critical resources in the early emergency periods also will require monitoring instruments. As in the case of the countermeasure units, these crews must locate a safe route to their objectives within the general vectoring information from command. After arrival at the objective, detail monitoring operations will be required to determine the permissible stay time of the operational crews and the need for radiological countermeasures at the site. Monitoring in this case essentially has the objective of defining the radiological situation for prolonged occupancy, whereas for the countermeasure units mentioned above, monitoring was for relatively short stay times required to complete a specific mission. Thus, monitoring of the critical resources will be relatively detailed but will be confined to a specific localized zone. The necessary radiological survey

activities of these units therefore form a second component of the mobile monitoring system. The information can be expected to be of considerably more detail than from the other operational units and should be more readily available at the command headquarters during the course of the survey. These units may require the support of radiological countermeasure operational units to place the critical resource in operational condition.

The third source of land mobile monitoring information is the operational units specifically designated to carry out this function. The units generally should be regarded as tactical or support groups to be deployed at the discretion of command. Areas to be surveyed and the survey techniques employed would be specified by command. Under some conditions the mobile units may operate in conjunction with other civil defense operational units which either have no organic equipment or require supplemental information that cannot be acquired by their own instruments.

Time-Phased Monitoring Procedures

Monitoring cannot be initiated until at least the cessation of fallout. During this period Operational Command should acquire radiological information from the local fixed monitoring system and shelters so that the early emergency operations and initial mobile monitoring efforts can be planned. From these data Operational Command should be able to establish the approximate areas in which mobile operations are required and can be carried out within the dose constraints specified. Operational Command should vector the mobile monitoring teams in much the same manner as other operational units.

In the attack and shelter phase mobile monitoring operations will likely be directed toward survey of the critical resource points and the sections of a local area in which shelters are situated. The initial monitoring efforts may be designed to provide indications of the feasibility of a range of possible alternative plans under consideration by Operational Command. Procedures to support this early planning may take the form of threshold monitoring, which consists of monitoring an area to determine if the field intensity level does not exceed a specified value and noting those points where it is exceeded. The method appears suitable when radiological information is required within a short time. Monitoring can probably be done directly from a moving vehicle at a rate up to 15-20 miles per hour with hand-held instruments. A typical application of this form of monitoring would be to determine the feasibility of evacuation operations, in which the maximum injury state reached by the evacuees in moving through an area could be estimated on the basis of the specified threshold dose and the time required to move through the area.

The ultimate decision as to the feasibility of an operation depends upon many factors in addition to the radiological situation. The accuracy and detail to which these additional factors are known and can be taken into consideration in planning an operation should characterize or limit the resolution of radiological information.

Threshold monitoring in a sense can be considered as the first order of magnitude increase in accuracy of area monitoring over the fixed system. It can be used to quickly differentiate the regions within the operational area in terms of the potential hazard to people within the area and to define the boundaries between the various hazard-state regions as suggested in Figure 9. The threshold levels to be monitored will of course change with time and must be established by command at the initiation of the survey. To differentiate the boundary between the noncritical and nominal hazard-state areas, for example, in a survey made for purposes of re-entry two days after cessation of fallout would require a radiation dose-rate threshold considerably higher than that for a survey made one week later because of the vastly increased age of the fallout material.

In the later portions of the attack and shelter phase and throughout the initial recovery phase, mobile monitoring efforts would be directed toward providing detailed information for the planning and execution of recovery operations. Radiological information will be required for scheduling of decontamination operations, for specification of stay times in production plants and other installations which will be continuously occupied, and for determining the time at which the general population can return to their homes.

Mobile monitoring teams would likely carry out a point-by-point survey on a regular preplanned grid specified by Operational Command. This form of survey can be regarded as the final phase of civil defense monitoring for whole-body gamma radiation. In the initial recovery phase it would probably be carried out first by vehicle-equipped crews and subsequently by walking survey parties. The latter most likely would operate in close cooperation with decontamination and other operational units. For moderately accurate point reading, measurements can be taken from vehicles at designated points. This, of course, does not represent the free-field measurement because of the shielding of the vehicle. More accurate readings require that the meter operator leave the vehicle and record the intensity level at least 30 to 50 feet from it. Obviously, operating in this manner will increase the time required to monitor an area by a considerable factor.

Monitoring Equipment

Monitoring equipment used by mobile monitoring teams and civil defense operational units generally should have the features included in most existing radiological instruments. For example, they should be lightweight, portable, shock resistant, and otherwise easy to handle and maintain. Generally, emergency operations and monitoring would not be expected to take place in fields exceeding dose rates of approximately 50 roentgens per hour. A stay-time of four hours in fields of this or higher intensities would result in a dose in the critical injury class. It would appear that operations of any meaningful significance normally could be expected to require at least four hours, and only under extraordinary circumstances would operational units be vectored into areas where they would receive doses in the critical injury class. Therefore, the maximum range of gamma dose-rate survey instruments for most applications need not be greater than 50 r/hr.

The minimum scale of the instruments is established by the monitoring requirements in the late initial recovery and reconstruction phases to support decontamination operations and other monitoring functions which take place in fields of relatively low dose rates. The range of field intensities of interest are those established by the dose limit of the nominal injury class. The NCRP indicates that a protracted exposure up to about 1.5 r/day over a year should not result in disability. In this case then a maximum low-scale range of 0.1 r/hr should provide adequate information. From the point of instrument design on a decade principal, however, a low-scale range of 0.05 r/hr may be more desirable and is not objectionable from an operational basis. Moreover, for survey and control of areas which were not contaminated, peacetime dose standards should be maintained. In this case, instruments of 0.05 r/hr or less would be required. The accuracies of these instruments, as discussed in Section III, should be in the order of ±50 percent.

Each monitoring team and operational unit should be equipped with personnel dosimeters. Because the members of the units will likely be moving about within the operational area, each man will be exposed to dose-rate fields of varying magnitudes. Therefore, each member of the unit should be provided with a dosimeter. As in military practice, the members of the unit should have a nonself-reading instrument and the unit captain should have a self-reading device. These instruments should have a capacity in the order of 200 roentgens, the critical injury class lower dose limit. Conventional dosimeter accuracies of about ±35 percent should be adequate.

Finally, in the reconstruction phase personnel assigned to work in areas where radiation tends to persist should be provided with dosimeters in the range of 25 roentgens. Instrument accuracies can be in the order of ±35 percent.

Cost

The cost of a mobile monitoring system is more difficult to define than the costs of other monitoring systems. The instruments used in mobile systems have wide application throughout all phases of recovery. Meters for in-shelter monitoring can be used in mobile surveys, for example, after their need in shelters has ceased. Similarly, these same instruments can be used by decontamination and other operational units. The organic monitoring equipment of nonradiological countermeasure operational units has similar multiple uses. Because of these conditions, the cost of mobile monitoring probably should be included within the program cost of hand-held survey instruments and dosimeters which are required to support over-all civil defense recovery procedures throughout the emergency. Specification of instrument requirements cannot be adequately derived until completion of survival and recovery plans by Operational Commands.

Unit costs of instruments for use in mobile monitoring and by operational units have been developed and provide a basis on which total system costs can be derived after requirements have been determined. Typically, unit costs of survey instruments are \$25, and the cost of dosimeters is \$5.[17] The unit costs for maintenance lies in the range of \$4.50 for survey instruments and \$0.50 for dosimeters.[18] Total maintenance costs depend on the rate and type of failure of the instruments. Survey instruments and dosimeters have been shown to fail at annual rates of about 10 and 0.3 percent, respectively.

VIII CONCLUSIONS

This analysis has been directed toward the general design concepts and operational procedures of radiological monitoring systems to be implemented in the late 1960 period and beyond. The system characteristics are derived from the information requirements which flow from the functions ascribed to the elements of the civil defense organization. While these functions are basic to the civil defense survival and recovery operation, the organizational element to which these functions are assigned is subject to over-all policy considerations of civil defense. Thus, if in the evolution of policy in future time periods the assignment of responsibility to the various organizational elements is markedly different from those developed here, the information requirements of the elements and the radiological monitoring systems to support them would undergo concomitant change. Moreover, the radiological information requirements defined in this report are considered to be the minimum requirements necessary for the organizational elements to carry out their functions efficiently. These requirements are also subject to policy and other considerations. Many of the functions could be discharged with less radiological information than has been indicated here, although the efficiency of performance likely would be restricted.

The emphasis was directed toward requirements for radiological information although, of necessity, the broader requirements for other types of information were considered to the degree necessary to establish a basic context into which radiological information requirements could be integrated. More refined and detailed analyses of the requirements for other types of information and the functions which they support may cause some changes in the radiological information requirements developed here. Such changes, of course, would alter the design and operational procedures of the monitoring systems as discussed in this report.

Radiological monitoring systems are inherently systems to provide support for civil defense survival and recovery operations. In general, therefore, the design and implementation of monitoring systems should follow the development of operational plans and programs, such as those for shelter construction and stocking and fire fighting and control. The requirements for radiological information to carry out these actions dictate the characteristics of a monitoring system. To justify the monitoring systems developed in this report, therefore, the civil defense operational capability identified herein should be either in existence or at least under a time-phased development so that monitoring systems can be coordinated with the growing capability. In general, the implementation of the monitoring systems considered in this study most likely could be carried out within the present civil defense policies and plans.

As a result of the work on radiological monitoring, six problem areas toward which research and planning efforts might profitably be directed have been identified. These can be summarized as follows:

1. Derivation of the requirements for information to support civil defense functions at all organizational levels throughout the emergency and recovery period.

2. Preparation of local plans for survival and recovery operations.

3. Improvement of reliability and operational readiness of monitoring instruments.

4. Determination of the characteristics of feasible communication systems to support civil defense.

5. Development of methods to incorporate radiological and other information into an integrated postattack damage assessment system.

6. Analysis of certain radiological monitoring problems in depth.

Some of these do not apply specifically to radiological monitoring but rather encompass far greater portions of the total civil defense effort. Moreover, finding solutions in most of these problem areas is viewed as long-term and continuing tasks. A number of these problems can be divided into two parts. The first is the long-term view which involves establishing the goals toward which civil defense should progress in the next five to ten years. The second part might be described as a problem in phasing from the present civil defense structure to the established future goals. Analyses of this type would be directed toward devising effective methods of countering the short-term civil defense threat while ensuring that the equipment purchased and the organizations established will have the greatest possible utility at times beyond the immediate period.

The need for deriving the information requirements to support civil defense functions is perhaps the most critical of the six points. It was necessary at the beginning of the work to examine the functions of the elements of the Civil Defense organization and the character of the radiological information required to carry out these functions before efforts could be directed specifically toward the problem. Once this was done, the general design and operational configuration of monitoring systems and equipment could be investigated within a meaningful framework. Consequently, rather than assume what dose-rates should be reported to a command post and the frequency and accuracy of these reports, it was possible to specify these requirements from the function and operational capability of the particular organizational element involved.

Specifying the content of radiological information to support civil defense functions requires consideration of the characteristics of other types of information which are also needed. That is, decisions cannot be made on the basis of radiological information alone. The accuracy, time of acquisition, and related dimensions of radiological information must be considered with respect to these same parameters as applicable to other classes of information with which the dose and dose-rate data will be combined to make planning and operational decisions. Despite the fact that fallout is an extremely serious threat, there appears to have been a tendency in the past to overemphasize the need for radiological information at the various command headquarters. The concern of civil defense agencies over the fallout problems in a postattack environment certainly is not misplaced. However, because of this great interest, the attention which has been directed toward the establishment of requirements for information describing other hazards and reports of the status of the population and the capability of the civil defense units to actually carry out operations does not appear to have been kept in balance.

In view of these conditions, a complete review of the total information requirements to support civil defense functions is of great importance and need. This review should consider the variation of civil defense functions and the resulting information requirements both over time as the emergency and recovery situation changes and over the entire civil defense organization. The relationship among the organization elements should be examined to determine those times when information requirements of one element can be satisfied by another element in contrast to the periods when each organizational element may need to acquire operational intelligence independently. The inherent constraints on the accuracy and associated characteristics of each class of information should be examined and assessed for its effect on other classes of information with which it is combined to support a civil defense function. This process should result in over-all planning guides for the development of information and intelligence systems which could provide meaningful and balanced command and operational information throughout the emergency and recovery period.

The preparation of local operational plans for survival and recovery is basic to the success of civil defense. In the final analysis this task can only be accomplished by local command units in conformance with guidance from the national organizations. These plans should be prepared on a contingency basis as a function of the degree of contamination of the local area, as well as other hazard situations. Separate plans, for example, might be prepared for initial contaminations of 300, 1,000, and 3,000 roentgens per hour; similarly, contingency plans should be developed for fires, and perhaps for various damage levels from direct effects. Planning of this type is, of course, not uncommon in local areas for natural disasters and conventional hazards.

National guidance for these efforts has taken and should continue to take the form of planning manuals and review of the actual plans prepared by the local civil defense organization. Various manuals for guidance of civil defense planning have been published in the past five or more years. These have been utilized to varying degrees by local organizational elements. Often, however, such publications tend to present the theoretical aspects of the problem or operational situation rather than a straightforward, how-to-do-it treatment. Moreover, the manuals have a tendency to restrict planning guidance to selected situations rather than to cover the full scope of possibilities. Therefore, a long-term and continuing effort should be directed toward the development of planning manuals and associated instructional material for the use of local civil defense organizations in the development of their survival plans.

Manuals typified by the Army/Navy publication Radiological Recovery of Fixed Military Installations,[7] April 1958, should provide a suitable point of departure. This manual generally presents the core of the required information without undue space being allocated to extraneous introductory or peripheral material. Sample calculations and representative operational situations are shown to assist in interpretation of the general guidelines to the specific situation, where planning is restrained by the actual limitations in equipment and trained personnel. Similarly, portions of the material in Carl Miller's Fallout and Radiological Countermeasures,[10] especially Reports 4, 5, and 6, illustrate the type of material which should be of great value in any planning aid.

A major effort appears to be needed in finding ways of improving the operational readiness of the present and future monitoring instruments. The rate of failure of the instruments now on hand has been and most likely will continue to be disturbingly high. The design accuracy and ranges of most of the present instruments, however, appears to be entirely suitable. Thus, with respect to the design of future instruments, heavy emphasis should be placed on reliability and failure-free components rather than increased accuracy.

The improvement of the operational readiness of the present instruments primarily involves questions of periodic maintenance, inspection, and related procedures. Whether any redesign and modification of present instruments to improve their reliability is feasible is difficult to say. At the conclusion of the national shelter survey the expected distributional pattern of a large part of the instruments should be known. From these data combined with instrument failure rates, the required calibration period of the instruments, and related factors, it should be possible to define the necessary maintenance and inspection system to keep the monitoring system in a satisfactory state of readiness.

A key factor in any civil defense operation is, of course, communication. In any examination of information requirements, as suggested previously, an accompanying review of the characteristics which would be required in a communication system to carry this information would be of great importance. As the requirements for information are developed, a concomitant analysis should be made to determine if the communication system to provide the necessary traffic capacity, speed, and similar characteristics is feasible. Such an analysis would tend to constrain the information requirements which would be established within realistic limits of operable communication systems. Typical problems which would require examination are indicated by the following two examples.

(1) a study of system survivability should cover the problems of equipment and network design and operational procedures both to reduce insofar as possible the loss of communication facilities from direct weapon effects and to recover from these losses as soon as possible after the attack. A priority schedule of information requirements would provide the basis on which to judge the need for survivable facilities.

(2) many of the civil defense communication requirements during war probably will be satisfied by systems used for other purposes during peacetime. The degree to which these existing systems can be rapidly converted to meet civil defense requirements should be determined in order to estimate the extent to which communication systems specifically designated for civil defense must be established and maintained in peacetime. This problem should be examined with respect to all organizational levels. Needless to say, cost would be a very important consideration in this analysis.

The fifth problem essentially is related to the information requirements at the national level. There appears to be a clear need for the investigation of methods of integrating all attack and postattack damage assessment and status-of-forces information into a unified system. A number of monitoring systems which are either in existence or planned for installation in the next few years have been developed to acquire information about one aspect of an attack. These systems usually are needed to support a particular civil or military function and are designed to satisfy this need. As might be expected, however, the data acquired by these various monitoring systems are in some respects complementary and, when taken together, can provide a considerably more comprehensive understanding of the attack situation. For example, the NUDET system is being designed to provide information on ground-zero location, yield, and other weapon parameters; radiological monitoring systems are designed to provide fallout information once the material is on the ground. The design and operational procedures of these two systems appear to have been considered independently of each other. However, for purposes of fallout warning, it would seem that considerably more accurate information could be developed by merging the information from these two systems in combination with fallout wind predictions than by

the use of only one or two of the three factors. Again, if a burst was such that the NUDET sensors could not determine the expected magnitude of fallout or the areas contaminated with suitable accuracy, radiological monitoring information would be of unquestionable help. The determination of the suitability of and need for integration of information in a postattack assessment system, of course, depends upon the information requirements to support the functions of civil defense.

Finally, the sixth problem area involves further consideration of radiological monitoring. The course of development in this field depends to some extent on the degree to which findings of all contractors contribute to the solution of the total problem of monitoring. Whether the combined results can lead directly to a detailed engineering design effort is difficult to say. This report suggests a number of problem areas which could be pursued further. Generally, these efforts would be directed toward establishing the detailed specification of various elements of a monitoring system whose limits or ranges of interest were defined in the report. These problems include the following:

1. Define the critical resources of the nation which should be included in the coverage of a fixed monitoring system and specify the most suitable base for aggregation. Identify the resources which may require specialized monitoring facilities.

2. Investigate problems of fixed monitoring stations, including the feasibility of monitoring fields of 10,000 r/hr and higher, site availability and design criteria, and station equipment design. Determine and judge the merits of the alternatives in operation of a fixed system, such as analog versus digital data, automatic reporting in contrast to interrogate-respond procedures, and manual versus automatic monitoring stations.

3. Examine the possible variations in the configuration of the communication system of a fixed monitoring system with regard to network vulnerability and survivability, cost, and associated elements.

These, in general terms, are suggestions for the direction in which some of the civil defense research effort might proceed. They are offered here as a concept of some of the more significant problems facing civil defense.

REFERENCES

1. Strope, W.E., Radiological Defense Measures as a Countermeasure System. USNRDL-TR-74, February 1956.

2. National Committee on Radiation Protection, Exposure to Radiation in an Emergency, Report #29, January 1962.

3. The Effects of Nuclear Weapons, U.S. Atomic Energy Commission, 1962, p.447.

4. Lee, H., Estimating Cost and Effectiveness of Decontaminating Land Targets, Volume I, Research and Development Technical Report, USNRDL-TR-435, June 1960.

5. Kleinecke, D.C., and M. Hawkins, Irregularities in Local Fallout, CDRP-182-101, University of California, December 1961.

6. Corcos, G.M., On the Small-Scale Non-Homogeneity of Fallout Deposition, University of California Institute of Engineering Research, October 1958.

7. Radiological Recovery of Fixed Military Installations, NAVDOCKS TP-PL-13, Departments of the Army and the Navy, April 1958.

8. Laurino, R., Suggested Framework for Study of Atomic Defense Measures, USNRDL-TM-36, 1955.

9. Miller, C.F., Outline of Research Program Content for Civil Defense, 1962, Office of Civil Defense, December 1962.

10. ____________, Fallout and Radiological Countermeasures, Office of Civil Defense, 1962, and Volume I, Stanford Research Institute, February 1963.

11. Guide for Architects and Engineers, NP-10-2, Office of Civil and Defense Mobilization, May 1960.

12. National Plan for Civil Defense and Defense Mobilization, Office of Civil and Defense Mobilization, October 1958.

13. Operations Plan, San Francisco Disaster Council and Corp., October 1959.

14. Shnider, R. W., and E. S. Shapiro, Prediction of Casualties from Land Surface Nuclear Detonations, USNRDL-TR-109, U. S. Naval Radiological Defense Laboratory, August 1956.

15. LaRiviere, P. D., The Relationship of Time of Peak Activity from Fallout to Time of Arrival, USNRDL-TR-137, U. S. Naval Radiological Defense Laboratory, February 1957.

16. Thompson, Philip D., Numerical Weather Analysis and Prediction, The Macmillan Company, New York, 1961.

17. Catalog of Fixed Average Unit Prices for Emergency Supplies and Equipment, Office of Civil and Defense Mobilization, Fiscal Division, Budget and Fiscal Office, June 1961.

18. Witzel, F. D., Logistical Aspects of Existing Radiological Monitoring Instruments, prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, February 1963.

STANFORD
RESEARCH
INSTITUTE

MENLO PARK
CALIFORNIA

Regional Offices and Laboratories

Southern California Laboratories
820 Mission Street
South Pasadena, California

Washington Office
808 17th Street, N.W.
Washington 5, D.C.

New York Office
270 Park Avenue, Room 1770
New York 17, New York

Detroit Office
The Stevens Building
1025 East Maple Road
Birmingham, Michigan

European Office
Pelikanstrasse 37
Zurich 1, Switzerland

Representatives

Honolulu, Hawaii
Finance Factors Building
195 South King Street
Honolulu, Hawaii

London, Ontario, Canada
85 Wychwood Park
London 14, Ontario, Canada

London, England
15 Abbotsbury Close
London W. 14, England

Milan, Italy
Via Macedonio Melloni 40
Milano, Italy

Tokyo, Japan
911 Iino Building
22, 2-chome, Uchisaiwai-cho, Chiyoda-ku
Tokyo, Japan